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A COMPUTERIZATION OF SERIES 60
RESISTANCE AND SELF-PROPULSION MODEL TESTS
by
ARTHUR P. AMESSE

Thesis Supervisor
Philip Mandel

May 19, 1967

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A COMPUTERIZATION OF SERIES 60
RESISTANCE AND SELF-PROPULSION MODEL TESTS

by

ARTHUR P. AMESSE
Lieutenant, United States Navy

B.S., Hofstra College
(1959)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
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MASTER OF SCIENCE
IN NAVAL ARCHITECTURE AND MARINE ENGINEERING
AND
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 1967

Signature of Author ______________________________
Department of Naval Architecture and
Marine Engineering, May 19, 1967

Certified by ______________________________
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Accepted by ______________________________
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A COMPUTERIZATION OF SERIES 60 RESISTANCE AND SELF-PROPULSION MODEL TESTS

by

Arthur P. Amesse

Submitted to the Department of Naval Architecture and Marine Engineering on May 19, 1967 in partial fulfillment of the requirements for the Master of Science Degree in Naval Architecture and Marine Engineering and the Professional Degree, Naval Engineer.

ABSTRACT

The Series 60 resistance and self-propulsion model test results are represented by curve fitting methods which result in functions containing Chebyshev polynomials. The accuracy of the curve fitting method is discussed, and the range of validity of the functions is presented.

A computer program for the calculation of EHP and SHP for single-screw merchant ships with hull proportions falling within the range of the Series 60 is discussed in detail. Several examples in the use of the program are presented.

It is concluded that estimates of EHP and SHP can be calculated to within a tolerance in the neighborhood of 1% on the average, and with great certainty, to within a tolerance of less than 3% for any given speed.

Thesis Supervisor:	Philip Mandel
Title:	Professor of Naval Architecture

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LIST OF SYMBOLS

B	Beam in feet
B/H	Beam - draft ratio
C_b	Block coefficient
C_f	Frictional resistance coefficient (ATTC)
C'_f	Frictional resistance coefficient (ITTC)
ΔC_f	Frictional ship correlation factor
C_m	Midship area coefficient
C_p	Prismatic coefficient
C_t	Total resistance coefficient
EHP	Effective or tow rope horsepower
H	Draft in feet
L	Length between perpendiculars (LBP) in feet
LCB	Longitudinal center of buoyancy
LWL	Length on designed waterline in feet
L/B	Length - beam ratio
PC	Propulsive coefficient (EHP/SHP)
R	Resistance in pounds
Re	Reynolds number
S	Wetted surface area in square feet
SHP	Shaft horsepower
V	Speed in knots
v_s	Speed in feet per second
$V/\sqrt{LWL}$	Speed - length ratio
Δ	Displacement in long tons

LIST OF SYMBOLS (continued)

∇	Volume of displacement in cubic feet
ν	Kinematic viscosity in ft.^{2}/second
ρ	Density of water in lb. sec^2/ft.^{4}
$\otimes$	Midpoint of length between perpendiculars

I. INTRODUCTION

1. Foreword

The determination of the required horsepower necessary to fulfill the speed requirements of a new ship design is one of the many problems which faces the naval architect in the early stages of ship design. He must have some way of knowing what effect various choices of size, proportions, and fullness of the ship will have on the power required to propel the ship at the speeds he desires.

In determining this power requirement, the naval architect can draw upon his past experience in ship design and the results of specific isolated model tests which are published periodically in the various technical journals of the profession.

However, the results of experiments conducted on families of models, in which the different design parameters are varied systematically, are the naval architects' most valuable sources of reference in estimating the power required for his new design. The result of these tests are usually expressed in the form of design charts from which the naval architect, using interpolation techniques where necessary, can calculate the power requirements for a number of combinations of design parameters, and thereby make an intelligent choice of the best combination of parameters to give minimum power with due consideration for the other limitations of his design conditions. The Series 60 is such a family of models designed to aid the naval architect in the estimation of power requirements for single-screw merchant ships.

2. The Series 60 Model Tests

The research on Series 60 was carried out at the David Taylor Model Basin (DTMB) of the United States Navy. Experiments were conducted as part

of the Bureau of Ships Fundamental Hydromechanics Research Program during the years 1948 to 1960. The results were published in a series of papers presented before the Society of Naval Architects and Marine Engineers, and a final report, incorporating all of the information contained in the interim reports was published in July of 1963.(1)*

After a survey of current practice in the shipbuilding industry to ensure, as far as possible, that the series would cover the normal range of proportions of modern ships, proportions were chosen for five parent models of the Series 60. These proportions are listed in Table I below.

TABLE I

Hull Proportions for Five Parent Models of Series 60

Model No.	4210	4218	4221	4213	4214
C_b	.60	.65	.70	.75	.80
L/B	7.50	7.25	7.00	6.75	6.50
B/H	2.50	2.50	2.50	2.50	2.50
$\Delta/(L/100)^3$	122.0	141.4	163.4	188.2	216.5
$L/\nabla^{1/3}$	6.165	5.869	5.593	5.335	5.092
LCB as % of L from $⊗_{BP}$	1.5 aft	1.54 aft	0.55 aft	1.5 fwd	2.5 fwd

For any one block coefficient and LCB position, a total of nine models were tested in which the L/B and B/H ratios were varied, for a total of forty-five models. To cover the general spread of L/B, B/H, and $\Delta/(L/100)^3$ for

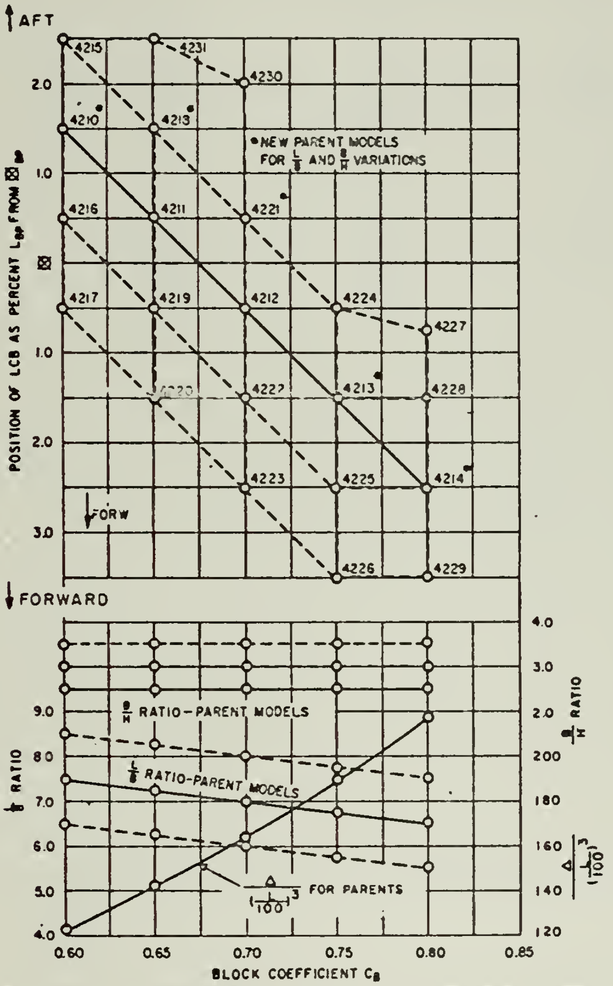
---

* Numbered references throughout the text are listed on page 44.

existing designs and the possible variation in LCB position, a grid was adopted as shown by the dotted lines in Figure I.

FIGURE I [*]

Variation of Proportions with C_b for Series 60 Models



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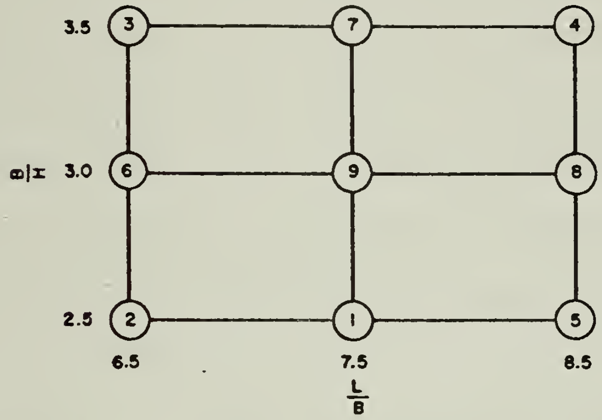
[*] From reference (1), page II-3

The pattern for a typical case ($C_b = .60$) is shown in Figure II.

FIGURE II *

Typical Variation of L/B and B/H Ratios for a Given Value of C_b



The midship section of the models had no deadrise in accordance with current practice. The relationship between C_m and C_p for the Series 60 is as follows:

$$C_m = 0.0857\ C_p + .925$$

And, since $C_b = C_p \times C_m$

$$C_b = 0.0857\ C_p^2 + .925\ C_p \qquad (1)$$

LWL for the Series 60 hull forms is related to L by the following simple formula:

$$LWL = \frac{406.75 \times L}{400.} \qquad (2)$$

---

* From reference (1), page II-3

The results of the Series 60 resistance tests are presented in the form of easy to use design charts, and in numerical point-by-point form in tables..

Values of total resistive coefficient (C_t) for forty-five ships of length between perpendiculars of 400 feet, and varying values of C_b, L/B, and B/H are presented in Tables B-1 through B-45 of reference (1). Utilizing the Froude assumption that the total resistance can be divided into two parts, the skin friction of an "equivalent plank" and the residuary resistance, the values of C_t include a skin friction coefficient (C_f) calculated for salt water at 59°F in accordance with the American Towing Tank Conference (ATTC) 1947 line*, and an additional allowance for ship correlation (ΔC_f) of + 0.0004 as recommended by the ATTC 1947. Methods for scaling the values of C_t for an arbitrary ship length will be discussed in Chapter IV.

Values of propulsive coefficient (PC or EHP/SHP) for forty-five ships of length between perpendiculars of 600 feet, and varying values of C_b, L/B, and B/H are also presented in Tables B-1 through B-45 of reference (1). Unlike the values of C_t, the propulsion data can not be corrected for variation in ship length. The choice of a 600 foot ship to illustrate the propulsion tests was made principally because it was considered more representative of modern ships than the 400 foot length chosen for the resistance presentation.** The propulsion data presented was obtained using a standard propeller diameter equal to 0.70 of the designed load draft.

Data for the effect of variation of LCB position on power requirements is by no means complete. Corrections to total resistance for variation of

---

* Also known as the Schoenher line.

** Reference (1), page VII-4.

LCB position for five values of C_b are presented in Tables 49 through 53 in reference (1), with only four or five different positions of LCB noted.

Although the propulsive data is presented for ships of 600 foot length, if the designer adopts the lines of Series 60, the position of LCB as used in the parent forms, and a propeller having the standard ratio of diameter to draft of 0.7, he can make a very accurate estimate of both the EHP and SHP of a ship for any particular selection of L, B, H, and Δ .

3. Previous Work in Series 60 Computerization

The development of a computer program for estimating EHP using the Series 60 results was first attempted by D. Khoushy in 1962.(2) This attempt represented the Series 60 by curve fitting methods to some extent e.g. wetted surface, but it relied exclusively on interpolative methods for C_t which are both cumbersome to program and highly consumptive of computer storage space*. Furthermore, the large amount of storage space required in this type of program made it unsuitable for use as an EHP or SHP subroutine in a larger program. It also should be noted that an interpolative scheme is not very efficient since the test results are not presented in a uniform manner, i.e. at low values of C_b models were tested up to a $V/\sqrt{LWL}$ of 1.10 whereas the higher values of C_b were tested up to a $V/\sqrt{LWL}$ of 0.80. This problem was avoided in the Khoushy work by discarding a large amount of Series 60 data in the low and high ranges of $V/\sqrt{LWL}$.

---

* The storage of approximately 6000 numbers is required for the Series 60.

Therefore, it was decided that curve fitting would be the most advantageous method of representing the Series 60 model test results in a computer program.

4. The Curve Fitting Approach

The curve fitting approach for representing the Series 60 results is very desirable since once a function is found, which represents the given data, one knows the error he can expect in predicting EHP and SHP using these derived functions. The fitting of curves through the Series 60 resistance data was started in early 1966 by T. M. Pitidis-Poutous. The basic theory of the curve fitting method employed was developed in reference (3) in 1965 with the mathematical derivation of ships lines being the focus of attention. This curve fitting method, as it applies to the representation of the Series 60 resistance data and its extension to represent the propulsion results for this work, is described in Chapter II.

II. DESCRIPTION OF CURVE FITTING METHODS USED FOR THE SERIES 60

The theory of the curve fitting methods used for representing the Series 60 model test results stated herein is largely adopted from reference (4).

Since the chart reading methods of the Series 60 are not suitable for computerization, it was decided to fit curves through the numerical results presented for C_t and PC (or EHP/SHP) in Tables B-1 through B-45 of reference (1).

In the Series 60, both C_t and PC are functions of four independent variables, i.e. $V/\sqrt{LWL}$, C_b, L/B, and B/H. Thus, either C_t or PC can be represented by an equation of the form:

$$Y = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{n=1}^{N} a_{nkji}\, \Phi_i\left(\frac{L}{B}\right) \Psi_j\left(\frac{B}{H}\right) \chi_k(C_b)\, \Omega_n\left(\frac{V}{\sqrt{LWL}}\right) \qquad (3)$$

and the problem reduces to determining the matrix of coefficients $[a_{nkji}]$ from the given data. If the coordinate functions Φ, Ψ, χ, and Ω are taken as ordinary polynomials, the above expression becomes

$$Y = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{n=1}^{N} a_{nkji} \left(\frac{L}{B}\right)^{i-1} \left(\frac{B}{H}\right)^{j-1} (C_b)^{k-1} \left(\frac{V}{\sqrt{LWL}}\right)^{n-1}$$

It can be shown that there are certain advantages to be gained if the coordinate functions are taken as the Chebyshev polynomials, with no additional complications.* The independent variables $V/\sqrt{LWL}$, C_b, L/B,

---

* See reference (5).

and B/H can be normalized in the range of -1 to +1 by the equations given in Table II, and the corresponding symbols used for the original, normalized, and computer program variables are given in Table III. The equations of Table II were derived on the basis of the limits of the Series 60 model tests.

Stipulations on the maximum powers I, J, K, and N, to be used in equation (3) are determined by the amount of data available from the Series 60 results. For example, each model was tested for three different values of B/H and L/B, therefore I and J must be equal to or less than 3. Models were tested for five different values of C_b, therefore K must be equal to or less than 5. Thus, the number of terms in the equation will be equal to or less than 45N. The value of N cannot be arrived at in the same way as I, J, and K, since each model was tested for twenty to thirty different values of $V/\sqrt{LWL}$, differing from model to model. If we assume, for the moment, that N = 10 would be adequate, we see that the determination of the coefficients a_{nkji} would involve the solution of 450 linear algebraic equations. This is virtually impossible, both from the numerical and computer storage points of view.

These considerations prohibited the use of a direct, 4-parameter fit, and indicated the necessity of a step-by-step technique.

Using the symbols for the normalized variables as defined in Table III, equation (3) becomes:

$$Y = \sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} \sum_{n}^{N} a_{nkji} \; \Phi_i(\mu) \Psi_j(\gamma) X_k(x) \Omega_n(v)$$

or

$$Y = \sum_{n=1}^{N} \sum_{\ell=1}^{L} A_{n\ell} \; F_\ell(\mu, \gamma, x) \; \Omega_n(v) \qquad (4)$$

TABLE II

Equations for Normalizing Independent Variables in Series 60 Range

$$v = 2.5 \frac{V}{\sqrt{LWL}} - 1.875 \quad ; \quad \frac{V}{\sqrt{LWL}} = 0.4v + 0.75$$

$$u = \frac{L/B - 7.0}{1.5} \quad ; \quad \frac{L}{B} = 1.5u + 7.0$$

$$z = 2.0 \frac{B}{H} - 6.0 \quad ; \quad \frac{B}{H} = 0.5z + 3.0$$

$$x = 10.0\ C_b - 7.0 \quad ; \quad C_b = 0.1x + 0.7$$

TABLE III

Correspondence of Original, Normalized, and Computer Program Symbols

Original Symbol	C_t	PC	C_b	B/H	L/B	$V/\sqrt{LWL}$
Normalized Symbol	Y	Y	x	z	u	v
Computer Symbol	CTM	PCM	CB	BH	BL	VL

where: $\ell = j + J(i-1) + IJ(k-1)$

and $F_\ell = \Phi_i(u)\, \Psi_j(z)\, X_k(x)$

The above substitutions reduce the four-dimensional matrix "a" to a two-dimensional matrix "A", which is easier for computations, and defines the problem more appropriately for the method to be used. For given values of u, z, and x, equation (4) can be written as:

$$Y_p = \sum_{n=1}^{N} C_{pn}\, \Omega_n(v) \qquad (5)$$

with

$$C_{pn} = \sum_{\ell=1}^{L} A_{n\ell}\, F_\ell(u, z, x) \qquad (6)$$

Equation (5) represents the variation of Y with respect to v for the p^th model, and the N coefficients (C_{pn}, n = 1, N) can be evaluated from the data in Tables B-1 through B-45 of reference (1), using the least-squares criterion:

$$\sum_i \left\{ (Y_p)_i - \sum_{n=1}^{N} C_{pn}\, \Omega_n(v_i) \right\}^2 = \text{MINIMUM}$$

by differentiating partially with respect to the unknown coefficients.

All models were fitted in this fashion, and the resulting equation for each model was evaluated at intermediate values in order to ensure that the polynomial had no undesired oscillations. In fitting the curves for C_t, it was found that a reasonably good fit was obtained with N = 10 (corresponding to a 9th order polynomial) and since this is rather high, the possibility of introducing a suitable weighting function was explored. Therefore, the fittings were repeated with the following two alternative

weighting functions assigned to C_t:

$$Y = \left(C_t \times 10^3\right)\left(V/\sqrt{LWL}\right)^3$$

$$Y = \left(C_t \times 10^3\right) / \left(V/\sqrt{LWL}\right)^2$$

The last alternative was found to give the best fit with N = 10 for most models. Going from N = 10 to N = 11, the maximum error experienced in $C_t \times 10^3$ only decreased from .025 to .024 for Table B-1 of reference (1).

Having obtained matrix $[C_{pn}]$ corresponding to equation (5) with p = 45 (number of models), matrix $[A_{nl}]$ was obtained by exact fit, i.e. L = 45. It should be mentioned here that a certain amount of regression could also be tried on this step of fitting, and this was actually attempted, but without success. The reason is that, although it might be possible to obtain a good fit for C_t or PC at a constant value of $V/\sqrt{LWL}$ with L less than 45, it does not follow that such a fitting could be applied successfully to the coefficients of the C_t - $V/\sqrt{LWL}$ equation (i.e. C_{pn}). Thus, direct 4-parameter fitting of the data could have produced an equation with less error and less terms, if it were possible numerically.

The values of PC were fitted in the same manner described above, but no weighting function was used.

The final equations obtained are as follows:

$$\frac{C_t \times 10^3}{\left(V/\sqrt{LWL}\right)^2} = \sum_{n=1}^{10}\sum_{l=1}^{45} A_{nl}\, F_l(\mu, \zeta, x)\, T_{n-1}(v) \qquad (7)$$

$$PC = \frac{EHP}{SHP} = \sum_{n=1}^{10}\sum_{l=1}^{45} B_{nl}\, F_l(\mu, \zeta, x)\, T_{n-1}(v) \qquad (8)$$

where

$$F_l = T_{i-1}(u)\, T_{j-1}(z)\, T_{k-1}(x)$$

$$l = j + 3(i-1) + 9(k-1)$$

$$T_p = p^{th} \text{ Chebyshev Polynomial}$$

The elements of the matrices $[A_{nl}]$ and $[B_{nl}]$ are read in as data in the main program, and are listed in Appendix A. These matrices form a compact computational package of 900 numbers for the calculation of C_t (400 ft. ship) and PC (600 ft. ship).

No attempt was made at fitting curves through the data for correction to total resistance due to variation of LCB position. The inadequacy of the data presented, as well as the erratic nature in which it behaves with $V/\sqrt{LWL}$, precluded the use of the curve fitting methods described above.

III. RESULTS OF CURVE FITTING METHODS USED AND RANGE OF VALIDITY

The results of the curve fitting methods used for C_t and PC were first tested by reproducing the data contained in Tables B-1 through B-45, i.e. for the forty-five models of the Series 60. The results of this test are presented in Table IV, where the maximum error, in percent, experienced in C_t and PC is noted for each of the forty-five models.

The maximum error experienced in C_t was 2.740% for the parent model 4218. The maximum error experienced in PC was 2.030% for model 4276. Although these figures appear prohibitive at first glance, it should be emphasized that these are the maximum errors experienced for any given model, and they occur at only one value of $V/\sqrt{LWL}$. The errors at other values of $V/\sqrt{LWL}$ for any given model are well under 1% in the great majority of cases. In fact, as can be seen from Table IV, the maximum errors experienced in C_t and PC for any given model are well below 1% in most cases. To illustrate this point further, plots of C_t versus $V/\sqrt{LWL}$ are presented in Figures III through VII, and plots of PC (or EHP/SHP) versus $V/\sqrt{LWL}$ are presented in Figures VIII through XII, for the five parent models of the Series 60. In these plots, the solid line represents the value of C_t and PC as calculated from equations (7) and (8) respectively, and the points represent the value at that $V/\sqrt{LWL}$ presented in the tables of reference (1), which are in error enough to be visually discernable on the scale used in making the plots. It is further noted that Figure IV represents the worst case experienced in fitting either C_t or PC.

As a second test, equations (7) and (8) were evaluated by generating 125 interpolate and extrapolate models, especially concentrating on

TABLE IV

Maximum % Errors Experienced in C_t and PC for the 45 Models of the Series 60

Series 60 Table No.	Model No.	C_b	L/B	B/H	Max. % Error in C_t	Max % Error in PC
B-1	4240	.60	6.5	2.5	.578	.853
B-2*	4210	.60	7.5	2.5	1.230	.648
B-3	4267	.65	8.25	2.5	1.515	.672
B-4	4264	.65	6.25	2.5	.340	.616
B-5*	4218	.65	7.25	2.5	2.740	.298
B-6	4243	.60	8.5	2.5	.701	.696
B-7	4244	.70	6.0	2.5	.531	.248
B-8*	4221	.70	7.0	2.5	.370	.402
B-9	4247	.70	8.0	2.5	.282	.552
B-10	4268	.75	5.75	2.5	.819	.386
B-11*	4213	.75	6.75	2.5	.824	.697
B-12	4271	.75	7.75	2.5	1.045	.682
B-13	4248	.80	5.5	2.5	.191	.372
B-14*	4214	.80	6.5	2.5	.381	.134
B-15	4215	.80	7.5	2.5	.243	.394
B-16	4252	.60	6.5	3.0	.885	.437
B-17	4255	.60	7.5	3.0	.714	.393
B-18	4254	.60	8.5	3.0	.477	1.261
B-19	4272	.65	6.25	3.0	.602	.529
B-20	4275	.65	7.25	3.0	.405	.446
B-21	4274	.65	8.25	3.0	.600	.516
B-22	4256	.70	6.0	3.0	.175	.277
B-23	4259	.70	7.0	3.0	.134	.590
B-24	4258	.70	8.0	3.0	.278	.573
B-25	4276	.75	5.75	3.0	.528	2.030
B-26	4279	.75	6.75	3.0	1.331	1.430
B-27	4278	.75	7.75	3.0	.923	.591
B-28	4260	.80	5.5	3.0	.248	.517
B-29	4263	.80	6.5	3.0	.166	.129
B-30	4262	.80	7.5	3.0	.082	.284
B-31	4241	.60	6.5	3.5	.541	.449
B-32	4253	.60	7.5	3.5	.411	.878
B-33	4242	.60	8.5	3.5	.459	.906
B-34	4265	.65	6.25	3.5	.634	.537
B-35	4273	.65	7.25	3.5	.418	.349
B-36	4266	.65	8.25	3.5	.493	.664
B-37	4245	.70	6.0	3.5	.203	.443
B-38	4257	.70	7.0	3.5	.435	.452
B-39	4246	.70	8.0	3.5	.312	.544
B-40	4269	.75	5.75	3.5	.223	.598
B-41	4277	.75	6.75	3.5	.506	.581
B-42	4270	.75	7.75	3.5	.919	1.275
B-43	4249	.80	5.5	3.5	.192	.542
B-44	4261	.80	6.5	3.5	.191	.577
B-45	4250	.80	7.5	3.5	.118	.303

* Denotes parent model

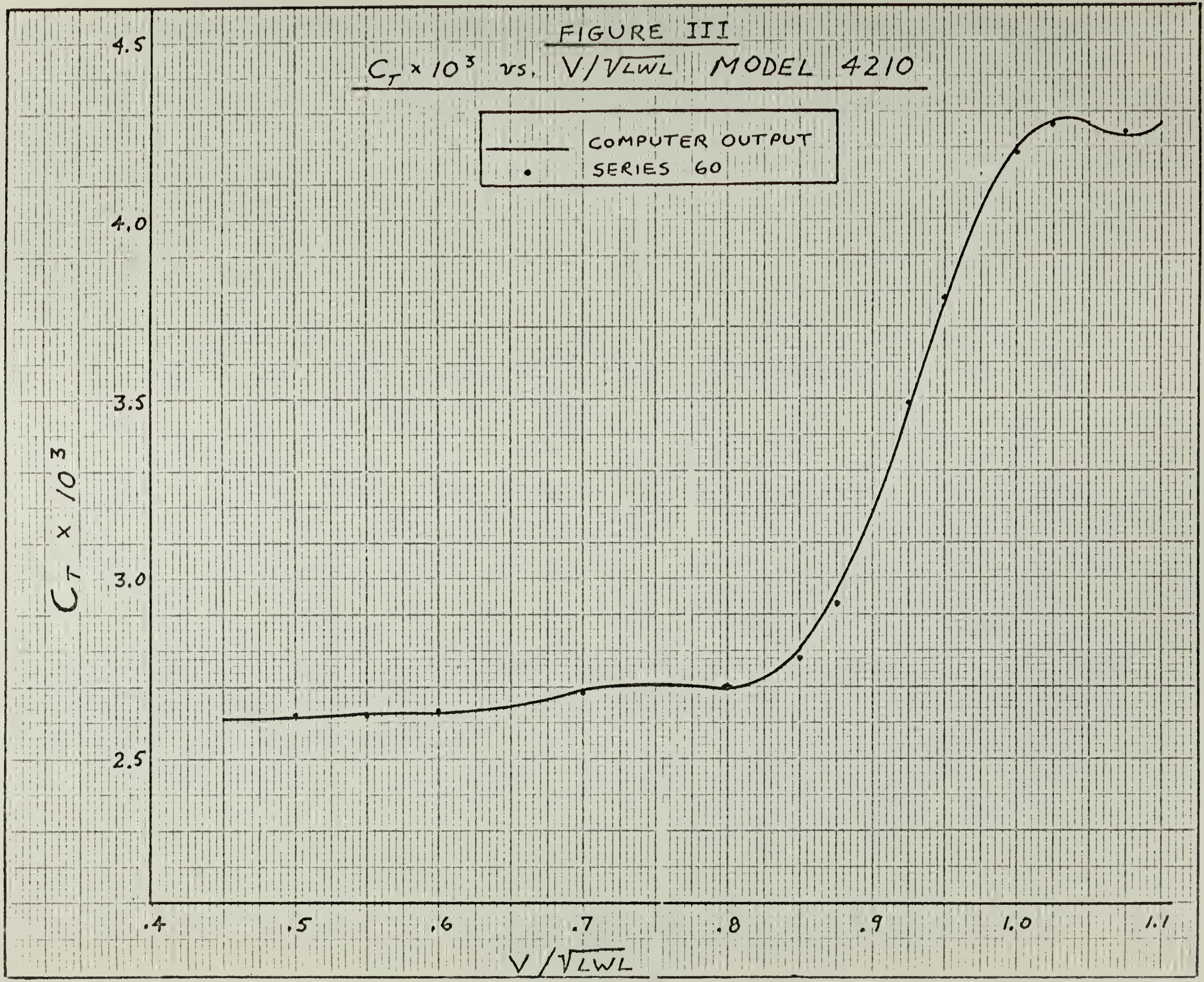
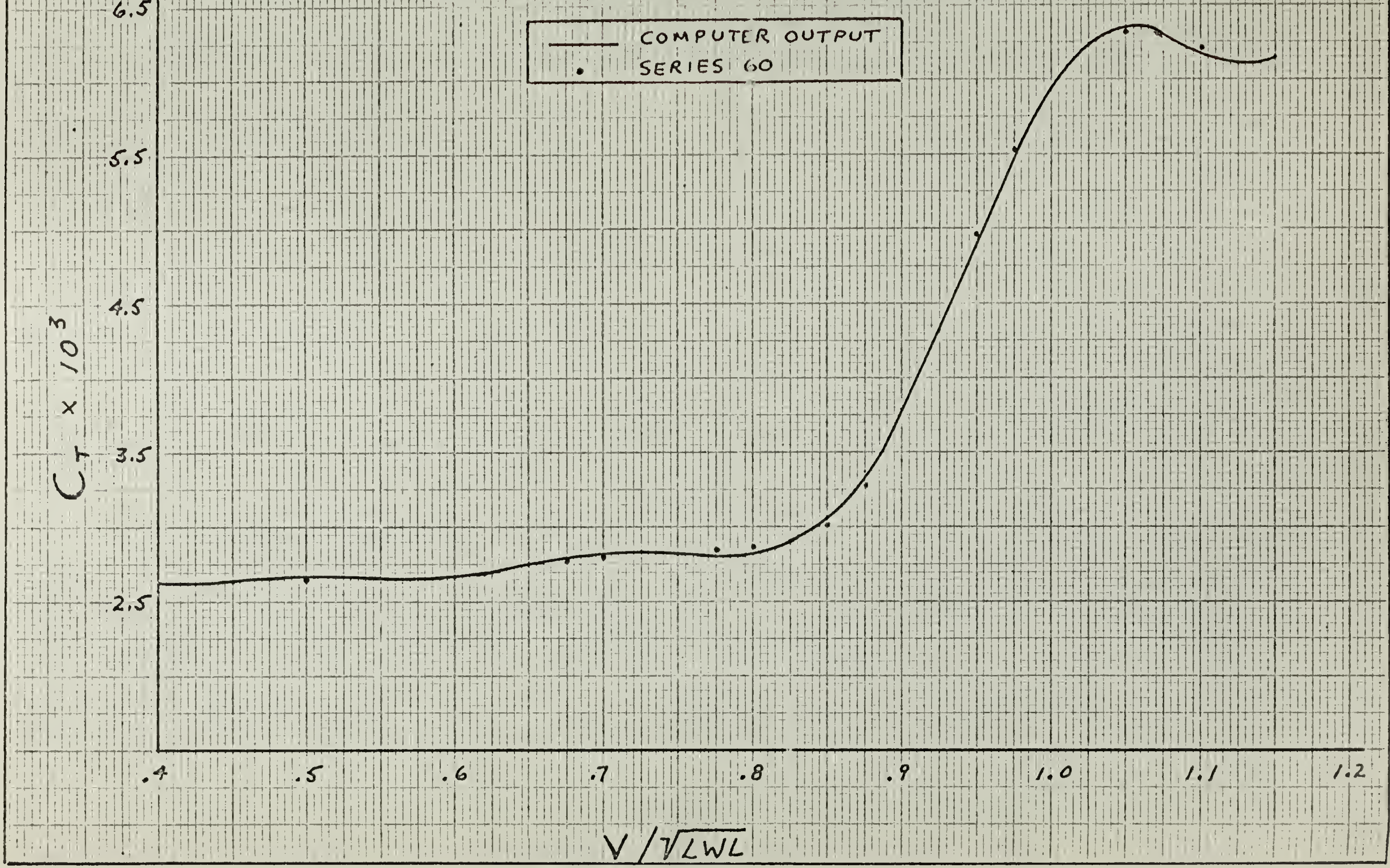


FIGURE III

$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ MODEL 4210

FIGURE IV

$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ - MODEL 4218



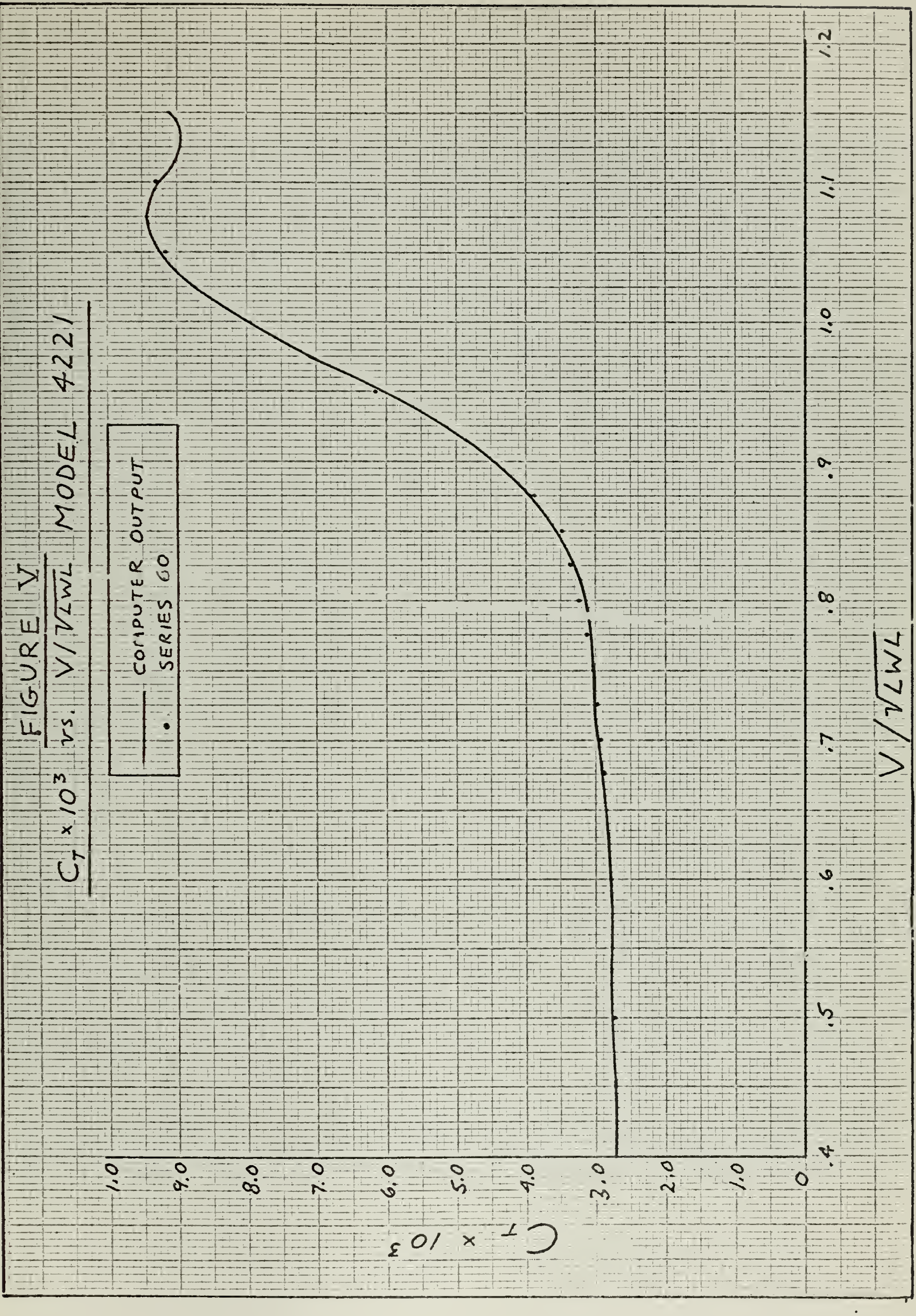


FIGURE V

$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ MODEL 4221

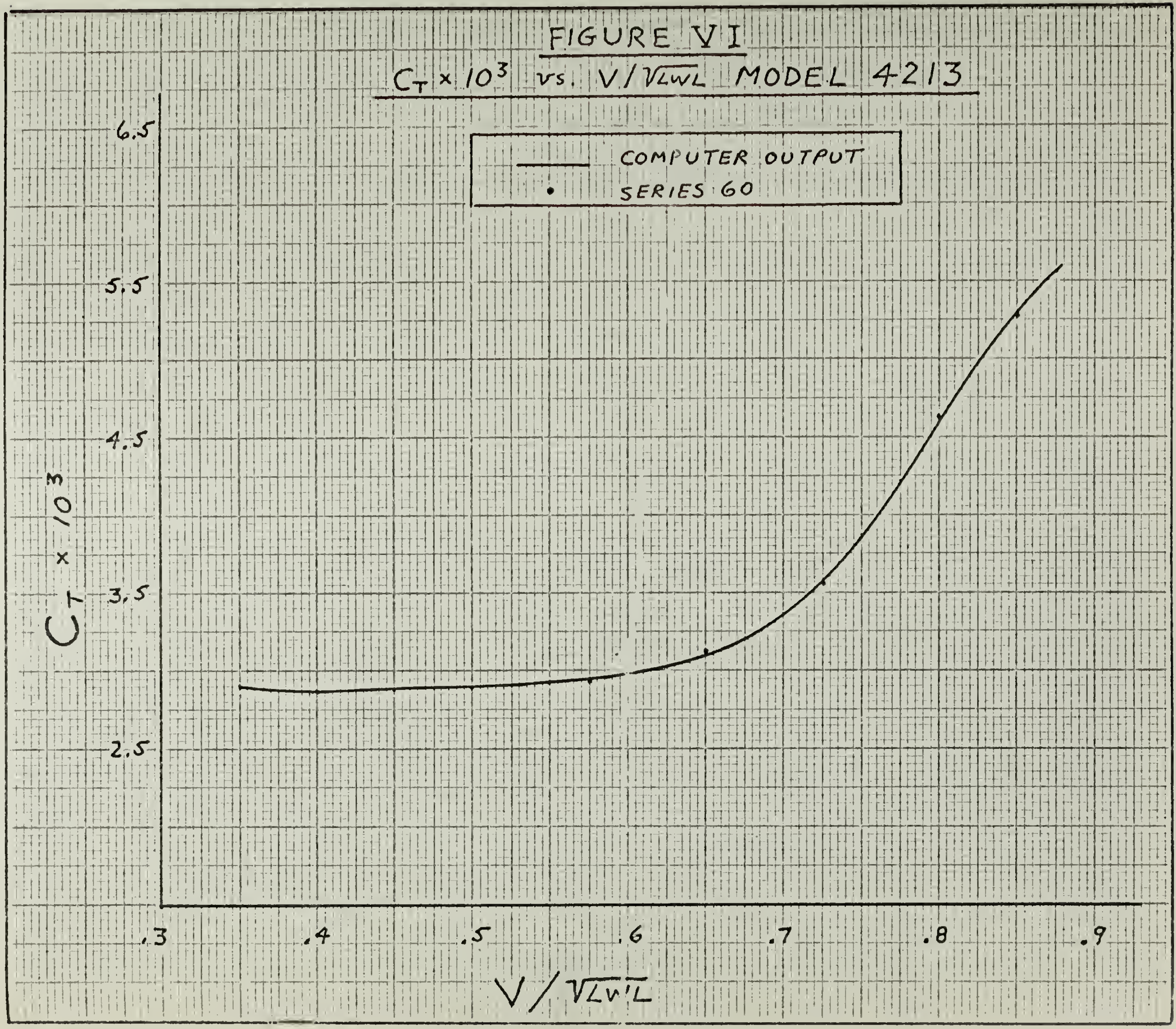


FIGURE VI

$C_T \times 10^3$ vs. $V/\sqrt{L_{WL}}$ MODEL 4213

FIGURE VII

$C_T \times 10^3$ vs. $V/\sqrt{LWL}$ MODEL 4214

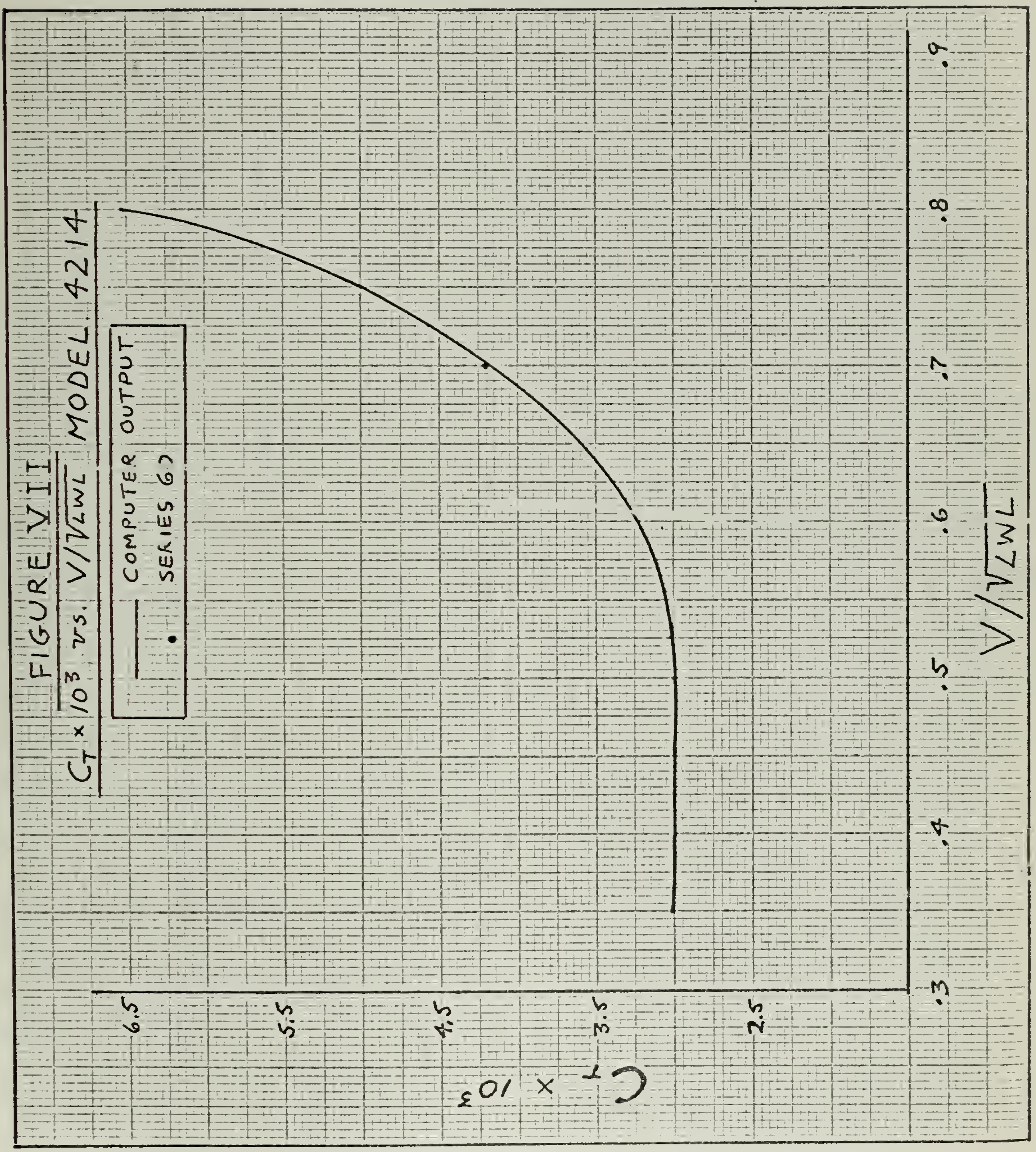


FIGURE VIII

EHP/SHP vs. $V/\sqrt{LWL}$ MODEL 4210

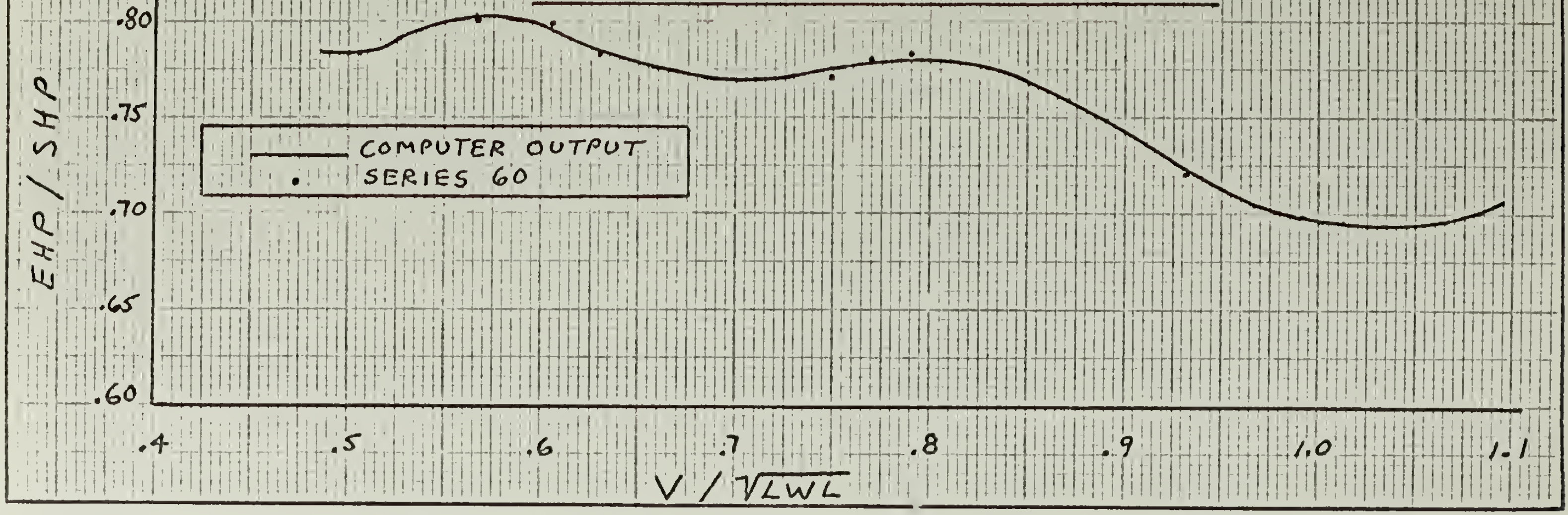
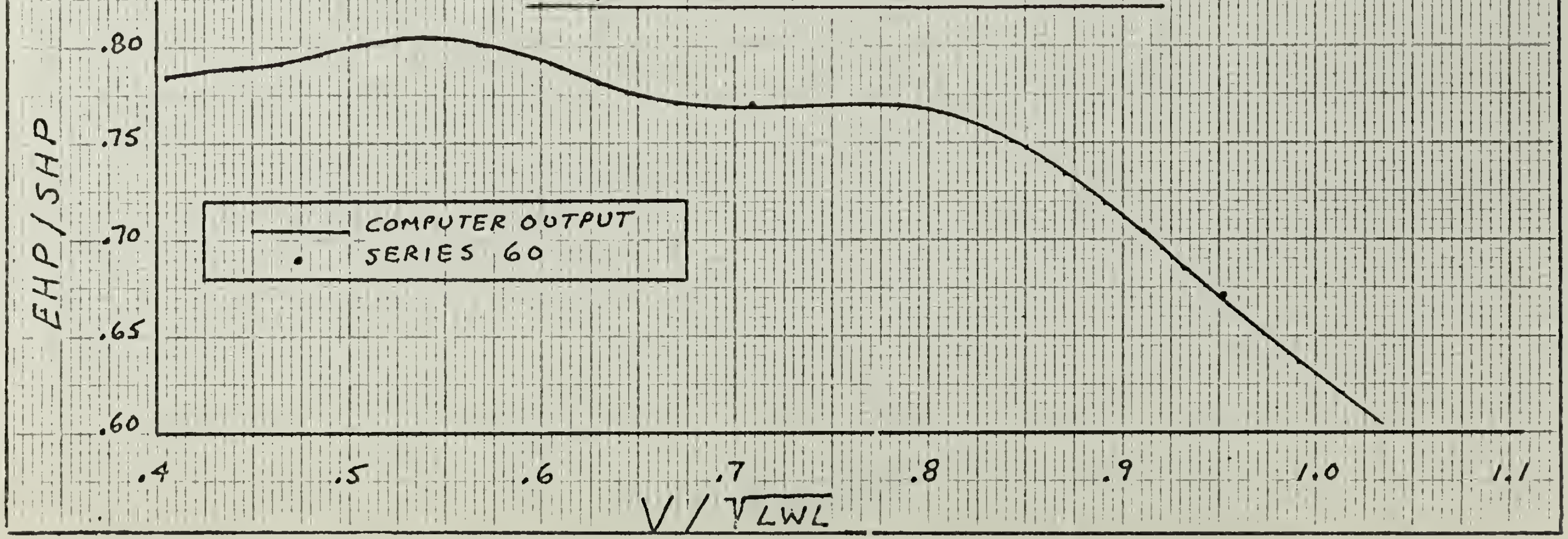


FIGURE IX

EHP/SHP vs. $V/\sqrt{LWL}$ MODEL 4218



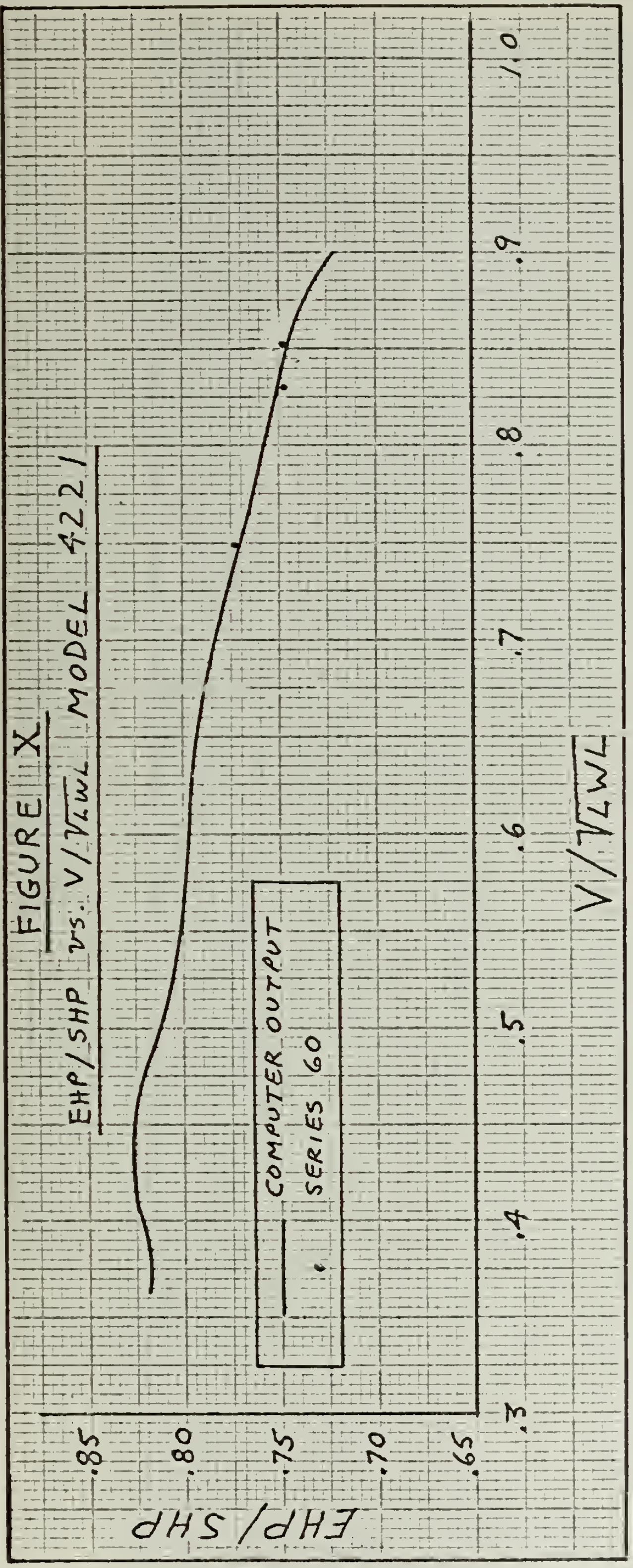


FIGURE X

EHP/SHP vs. $V/\sqrt{LWL}$ MODEL 4221

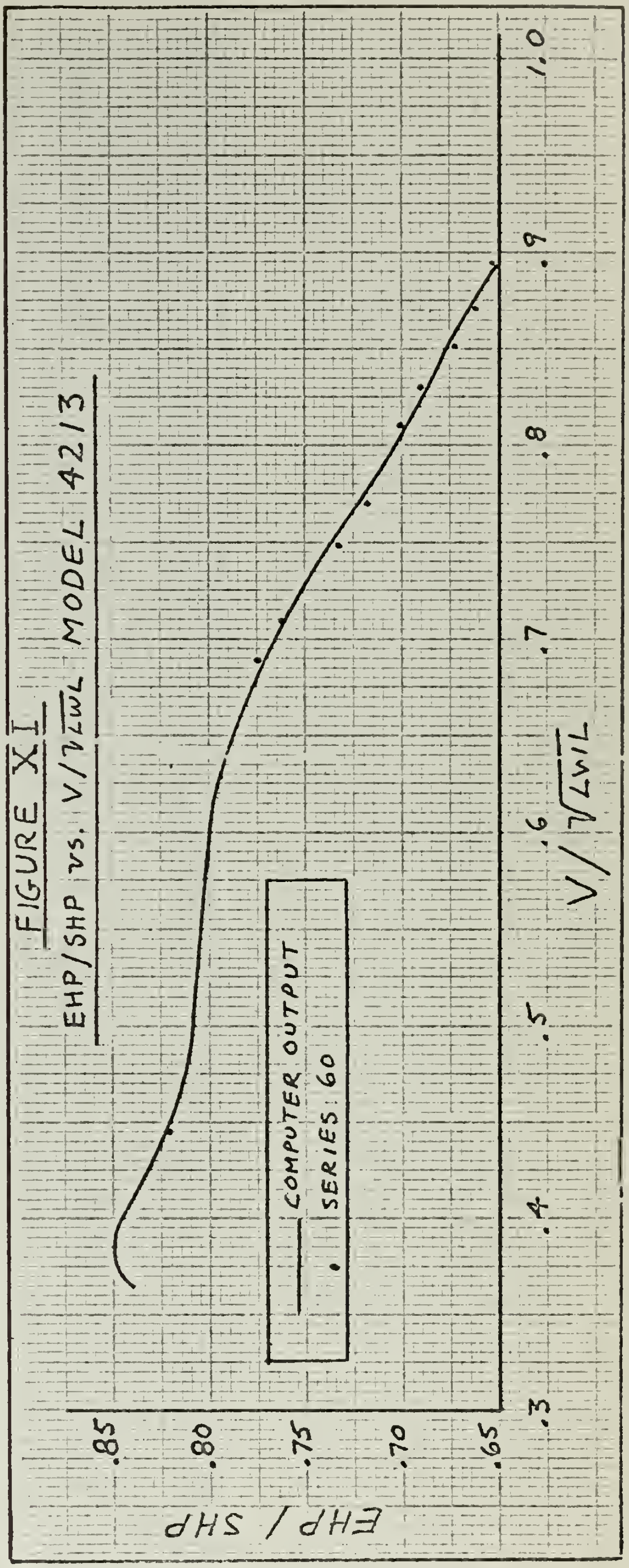


FIGURE XI

EHP/SHP vs. $V/\sqrt{LWL}$ MODEL 4213

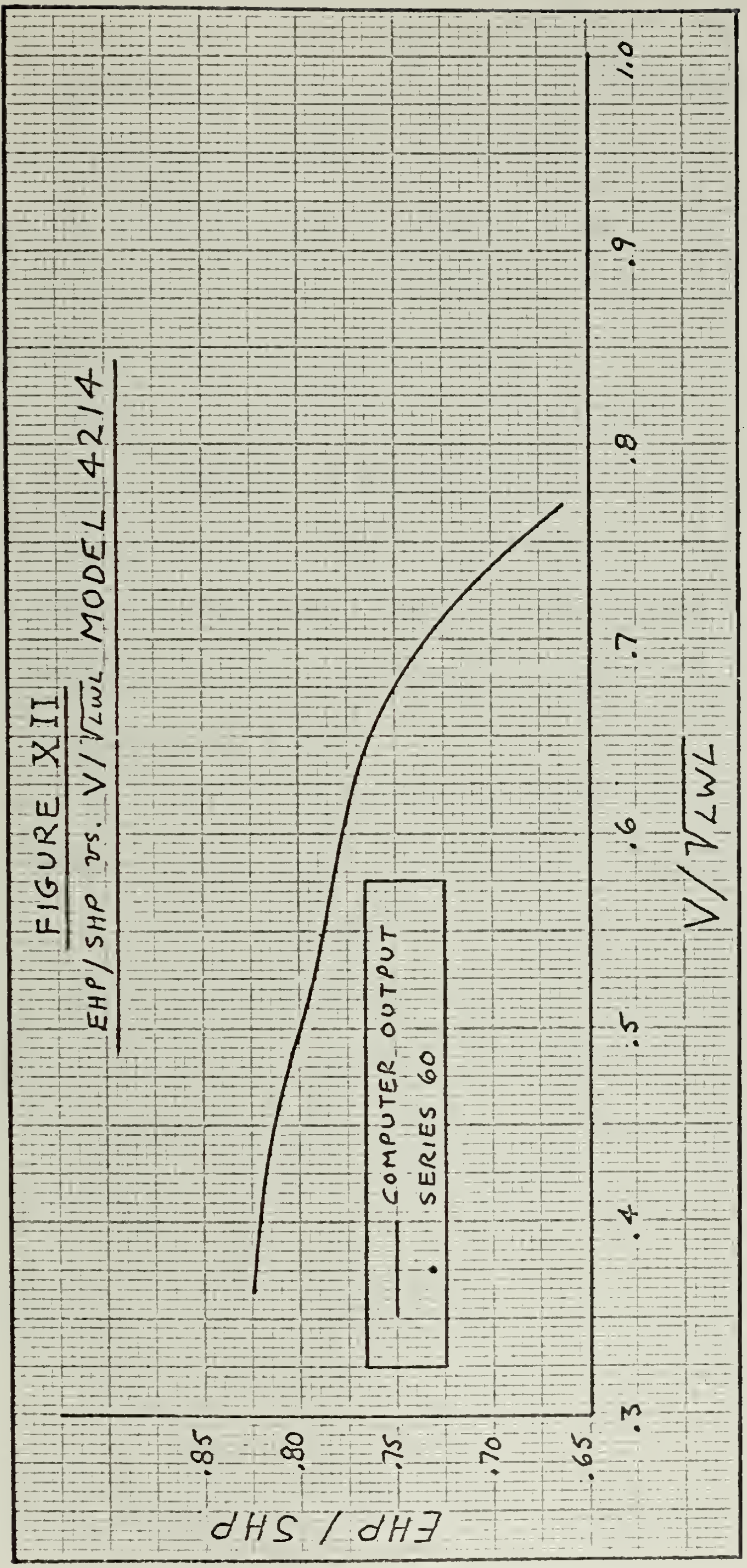


FIGURE XII

EHP/SHP vs. $V/\sqrt{LWL}$ MODEL 4214

intermediate values of the five Cb's used for the Series 60 models. This was done in order to determine the range of validity of these equations with respect to their four independent variables. It should be emphasized that the ranges of validity determined below are not just a result of the inadequacies of the curve fitting methods used; they are very much a result of the limits of the Series 60 model tests themselves and the range of data made available in reference (1).

The data presented in reference (1) is based on the use of three values of B/H, i.e. 2.5, 3.0, and 3.5. Since equations (7) and (8) rely on a second order interpolation scheme in B/H, which is the method suggested in reference (1) when using the design charts, there should be no discrepancies caused by this variable. It is also expected that a limited amount of extrapolation is possible in B/H.*

Similarly, there should be no discrepancies due to L/B since equations (7) and (8) rely on a second order interpolation scheme for this variable, which is also the method used by DTMB in the preparation of the Series 60 design charts. However, as can be readily seen from Figure I, there are limits (imposed by the proportions of the Series 60 models) on the range of interpolation possible in L/B. The range of interpolation in L/B is a function of C_b and can be expressed as follows:

$$(L/B)_{min} = 5.5 + \frac{8.0 - 10\ C_b}{2} \qquad (9)$$

$$(L/B)_{max} = 7.5 + \frac{8.0 - 10\ C_b}{2} \qquad (10)$$

---

* See example of the ship SCHUYLER OTIS BLAND in Chapter V.

A small amount of extrapolation beyond these limits should not cause trouble.

In producing the Series 60 design charts, a third order interpolation in C_b was used by DTMB. In equations (7) and (8) a fourth order interpolative scheme for C_b is used, which could produce slight discrepancies in interpolation and extrapolation. It is recommended that the program be used only in the range of $C_b = 0.60$ to 0.80.

The Series 60 model tests impose definite limits on the range of $V/\sqrt{LWL}$ permissible. For example, in testing equations (7) and (8) with the 125 models mentioned above, it was found that with $C_b = 0.775$, $B/H = 3.0$, and $L/B = 7.0$, the values of C_t and PC given by equations (7) and (8) dropped off sharply at $V/\sqrt{LWL} = .925$ and even went negative at $V/\sqrt{LWL} = .950$. This is understandable since at these values of $V/\sqrt{LWL}$ we are outside the range of results given by the Series 60 tests. Therefore, to avoid occurrences of this nature, a "trap" has been built into the EHP-SHP program described in Chapter IV, which puts limits on the value of $V/\sqrt{LWL}$ allowed, depending upon the value of C_b. These limits are presented in Table V.

TABLE V

Limits of $V/\sqrt{LWL}$ Allowed by Program

Range of C_b	$(V/\sqrt{LWL})_{min}$	$(V/\sqrt{LWL})_{max}$
$.600 \leq C_b \leq .612$	.45	1.10
$.612 < C_b \leq .625$	.45	.90
$.625 < C_b \leq .725$	.40	.90
$.725 < C_b \leq .775$	.35	.875
$.775 < C_b \leq .800$	.35	.800

Within the ranges of independent variables stipulated above, one can expect values of C_t and PC from equations (7) and (8) to agree with the published results of Series 60 to within 1%, with consistent reliability .

IV. DESCRIPTION OF THE EHP-SHP COMPUTER PROGRAM FOR SERIES 60

The program for calculating EHP and SHP using the Series 60 model test results was written in the FORTRAN IV language. A flow chart for the program, a listing of the FORTRAN statements, and the 900 elements of the matrices $[A_{nl}]$ and $[B_{nl}]$ mentioned in Chapter II are included in Appendix A. The following is a general description of the methods of calculation used. Detailed instructions for the use of the program are contained in Appendix C.

1. Inputs

First the elements of matrices $[A_{nl}]$ and $[B_{nl}]$ are read in as data. The number of ships to be calculated (NJOBS) and an identifying alphameric statement is then read. It takes three cards to describe each ship to be calculated. The first card describes the input mode (INOPT) for the ship to be calculated. The operator is afforded an option of one of two possible input modes for each ship.

a. Mode I

Entry is made with L, B, H, C_b, V_{max}, V_{min}, $V_{increment}$, ΔC_f, Position of LCB from ⊗ , S, φ, and kinematic viscosity.

b. Mode II

Entry is made with L, B/H, Δ, C_p, V_{max}, V_{min}, $V_{increment}$, ΔC_f, Position of LCB from ⊗ , S, φ, and kinematic viscosity.

2. Calculation of needed parameters

Using the input information, the program then calculates the remaining parameters required for executing the remainder of the program. For example, if the entry is made using Mode I, the program calculates Δ, B/H, C_p using equation (1), the Series 60 equivalent LWL using equation (2), the volume of

displacement ∇ , midship coefficient C_m, and L/B.

3. Normalizing hull proportion parameters

The program calculates the normalized hull proportion parameters for L/B, B/H, and C_b using the equations in Table II.

4. Trap to make sure $V/\sqrt{LWL}$ is within range of model test

The program calculates $V/\sqrt{LWL}$ maximum and minimum and ensures that these values are within the range of validity given in Table V. If they are not, the program alters V_{min} and V_{max} accordingly, until they are within the range.

5. Calculation of number of increments in V to be calculated

Using V_{max}, V_{min}, and $V_{increment}$, the number of different speeds (m) at which EHP and SHP are desired is calculated. There is a maximum of 100 different speeds allowed for each ship. If this number exceeds 100, the program keeps doubling $V_{increment}$ until "m" is 100 or less. If the operator desires EHP-SHP information for only one speed, m is set at one.

6. Calculation of V's, $V/\sqrt{LWL}$'s and normalizing $V/\sqrt{LWL}$

The V's and $V/\sqrt{LWL}$'s are calculated based on the V_{min} , $V_{increment}$ LWL, and m calculated above. The $V/\sqrt{LWL}$'s are then normalized using the equation in Table II. If $V_{max} = V_{min}$ and $V_{increment} = 0.$, only one speed is used.

7. Calculation of C_t for a 400 foot ship and PC for a 600 foot ship

The C_t for a ship of L = 400 ft. (C_{tM}) and PC for a ship of L = 600 ft. are calculated for each $V/\sqrt{LWL}$ using the normalized parameters determined above, and equations (7) and (8) respectively. Subroutine CEF* is used to

---

* See program listing in Appendix A.

evaluate the Chebyshev Polynomials for these equations.

8. Calculation of C_f for a 400 foot ship and C_f for a ship of length L

The Reynolds Numbers (Re) for the L = 400 ft. ship (Re_M) and for the ship of length L (Re_S) are calculated for each $V/\sqrt{LWL}$ by using equations (11) and (12).

$$Re_M{}^{*} = \frac{406.75 \times v_s}{1.2817 \times 10^{-5}} \qquad (11)$$

$$Re_S = \frac{LWL \times v_s}{\nu} \qquad (12)$$

The C_f's for the 400 ft. ship (C_{f_M}) and ship of length L (C_{f_S}) are calculated using the ATTC 1947 correlation line given in equation (13).

$$C_f^{-.5} = 4.132 \log_{10} (Re \times C_f) \qquad (13)$$

In the calculation of the C_f's, it is necessary for the program to use an iteration process, since C_f appears on both sides of equation (13). The initial estimate for this process is made by using the equation for the International Towing Tank Conference (ITTC) line, equation (14).

$$C_f' = \frac{0.075}{(\log_{10} Re - 2)^2} \qquad (14)$$

Equation (13) is recycled for 50 times, or until the C_f values converge to within a tolerance of 5.0×10^{-7}. Although this should not occur, if formula (13) does not converge, the program prints the error signal

---

* Note that LWL = 406.75 for a ship of 400 ft. length between perpendiculars, and that kinematic viscosity is for salt water at 59°F.

"SCHOENHER NO CONVERGE" with the speed at which the trouble was experienced.

9. Calculation of wetted surface (S) if not input

Ideally, the wetted surface (S), in square feet, is fed into the computer as input. However, if the wetted surface is not known at that time, the program will calculate an approximate wetted surface using equation (15).

$$S = 2.654 \, (L/B)^{.329} \, (B/H)^{.208} \, (C_b)^{-.0609} \, (\nabla)^{.666} \qquad (15)$$

This equation for approximating wetted surface for the Series 60 was developed by D. Khoushy in reference (2). This formula was tested extensively and compared to the contours for wetted surface calculation, Figures B-124 through B-126, in reference (1). It was found that this formula adequately represents the wetted surface contours of the Series 60, with the maximum error rarely exceeding 1.2%. Since wetted surface is a factor in calculating resistance, EHP and SHP, if wetted surface is not an input parameter to the program, one can expect errors in EHP and SHP due to the use of equation (15), in addition to the errors to be expected due to the use of equations (7) and (8) as discussed in Chapter III.

10. Calculation of C_t for the ship of length L, R, EHP, and SHP

The C_t for the ship of length L, (C_{t_S}), is calculated using equation (16).

$$C_{t_S} = C_{t_M} - C_{f_M} - 0.0004 + C_{f_S} + \Delta C_f \qquad (16)$$

Then the remaining calculations are trivial, namely:

$$R = 1/2 \rho S v_s^2 C_{t_S}$$

$$EHP = \frac{R v_s}{550}$$

$$SHP = \frac{EHP}{PC}$$

where PC is for a ship of L = 600 ft.

11. Calculation of LCB position from ⊗ as a percentage of L

The LCB position from ⊗ as a percentage of length between perpendiculars is calculated and presented in the output. It should be remembered here that corrections to R, EHP, and SHP for variation in LCB position from those of the parent model hull forms are not built into the program. Graphs for assistance in making these corrections, based on Tables 49 through 53 of reference (1), are included in Appendix B. The LCB position from ⊗ as a percentage of length between perpendiculars is calculated for entry to these graphs.

12. Output

The output for each ship calculated includes C_b, L/B, B/H, C_p, Cm, length between perpendiculars (LBP) in feet, LWL in feet, B in feet, H in feet, displacement (DISP) in tons, volume of displacement (VOL) in cubic feet, wetted surface (WSURF) in square feet, ΔC_f, water density ρ in $\frac{\text{lb. sec}^2}{\text{ft.}^4}$, kinematic viscosity (GNU) in $\frac{\text{ft}^2}{\text{sec}}$, LCB position as a percentage of LBP, and a tabulation of V, $V/\sqrt{LWL}$, R, EHP, PC, and SHP for each speed requested in the input. A statement is printed under this tabulation which reminds the user that the values are not corrected for variation in LCB position as explained above.

V. EXAMPLES IN USE OF THE EHP-SHP COMPUTER PROGRAM FOR KNOWN SHIPS

The final EHP-SHP computer program was tested with the parameters of six ships whose EHP-SHP characteristics are known. As a first test, the Series 60 equivalent of the ship SCHUYLER OTIS BLAND was chosen, since this was the ship used in Appendix D of reference (1) in illustrating a numerical example of the use of the Series 60 charts. It was also chosen since it illustrates the ability of the program to interpolate for intermdeiate values of C_b (0.651) and L/B (6.82) and to extrapolate outside the range of the Series 60 in B/H (2.444).

As a second test, the five parent models of the Series 60, with L = 600 feet, were chosen since complete information on their EHP and SHP behavior is presented in Tables 27 through 31 in reference (1), and they cover a variety of hull proportion combinations.

The results of these tests are discussed below.

1. Test using the ship SCHUYLER OTIS BLAND

As a first test on this ship, input Mode I was used with the wetted surface area of 39994.0 square feet as input. As a result, the computer output, Table VI, for EHP was a measure of the accuracy of equation (7). In comparing the computer program's EHP results with those resulting from the hand calculations carried out in Table D-3 of reference (1), it was found that the maximum error experienced in EHP was + 2.70% at $V/\sqrt{LWL} = .85$, while the average error experienced was + 1.19% . Although the average error of 1.19% is fairly gratifying, the maximum error certainly is not. However, referring to Table IV again we see that in using the hull proportions of the SCHUYLER OTIS BLAND we place ourselves in the neighborhood of parent model

TABLE VI

Computer Output SCHUYLER OTIS BLAND, Wetted Surface as Input

```
   9   TEST RUN OF EHP SHP PROGRAM

CB= 0.651    L/B= 6.818    B/H= 2.444    .CP= 0.662    CM= 0.983
LBP=  456.00 FT    LWL=   457.59 FT     B=    66.00 FT    H=    27.00 FT
DISP=  14915.33 TONS    VOL=    522036.56 FT**3    WSURF=   39994.00 FT**2
DELTA CF= C.0004000    RHO= 1.9904995 LB*SEC**2/FT**4    GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.000 PERCENT OF LBP AFT OF AMIDSHIPS.

 V (KTS)   V/RTLWL      R (LBS)      EHP (HP)    PC        SHP (HP)
  8.557    0.4000     22159.35       582.26   0.9302       625.96
  9.627    0.4500     28125.36       831.44   0.8091      1027.57
 10.697    0.5001     35482.00      1165.50   0.8185      1423.90
 11.767    0.5501     42740.56      1544.35   0.8333      1853.22
 12.837    0.6001     51097.96      2014.23   C.8228      2448.00
 13.907    0.6501     61709.68      2635.29   C.8023      3284.84
 14.977    0.7001     73426.81      3376.92   0.7907      4270.78
 16.047    0.7502     84243.62      4151.18   0.7901      5254.16
 17.117    0.8002     96300.19      5061.69   0.7858      6433.36
 18.187    C.8502    119834.44      6692.43   C.7663      8732.97
 19.257    0.9002    169401.37     10017.20   0.7270     13779.42

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE VII

Computer Output SCHUYLER OTIS BLAND, No Wetted Surface as Input

```
   9   TEST RUN OF EHP SHP PROGRAM

 CB= 0.651    L/B= 6.818    B/H= 2.444    CP= 0.662    CM= 0.983
 LBP=  450.00 FT    LWL=  457.59 FT    B=   66.00 FT    H=   27.00 FT
 DISP=  14915.33 TONS    VOL=    522036.56 FT**3    WSURF=  39651.54 FT**2
 DELTA CF= 0.0004000    RHO= 1.9904995 LB*SEC**2/FT**4    GNU= 0.128169995E-04 FT**2/SEC
 LCB IS 1.000 PERCENT OF LBP AFT OF AMIDSHIPS.

   V (KTS)    V/RTLWL       R (LBS)      EHP (HP)    PC        SHP (HP)
    8.557     0.4000      21967.97       577.21   0.9303       620.46
    9.627     0.4500      27881.64       824.20   0.8091      1018.61
   10.697     0.5000      35175.26      1155.37   0.8185      1411.55
   11.767     0.5501      42371.59      1530.97   0.8333      1837.16
   12.837     0.6001      50656.73      1996.77   0.8228      2426.76
   13.907     0.6501      61176.62      2612.44   0.8023      3256.33
   14.977     0.7001      72793.44      3347.69   0.7907      4233.30
   16.047     0.7501      83518.00      4115.31   0.7901      5208.77
   17.117     0.8002      95469.56      5017.90   0.7868      6377.68
   18.187     0.8502     118794.31      6634.18   0.7864      8650.82
   19.257     0.9002     157924.62      9929.66   0.7270     13658.64

  *** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE VIII

Computer Output Model 4210, L = 600 ft.

```
  9  TEST RUN OF EHP SHP PROGRAM

CB= 0.600   L/B= 7.500   B/H= 2.500   CP= 0.613   CM= 0.979
LBP=  600.00 FT   LWL=  610.12 FT   B=   80.00 FT   H=   32.00 FT
DISP=  26331.41 TONS   VOL=   921599.31 FT**3   WSURF=  60320.19 FT**2
DELTA CF= 0.0004000   RHO= 1.9904995 LB*SEC**2/FT**4   GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.500 PERCENT OF LBP AFT OF AMIDSHIPS.

  V (KTS)    V/RTLWL       R (LBS)       EHP (HP)     PC         SHP (HP)
  12.000     0.4858       62025.71       2285.57   0.7862       2907.00
  12.500     0.5061       67855.12       2604.56   0.7833       3325.19
  13.000     0.5263       73815.69       2946.68   0.7912       3724.31
  13.500     0.5465       79717.31       3304.66   0.7992       4135.09
  14.000     0.5668       85594.62       3679.73   0.8026       4584.66
  14.500     0.5870       91624.31       4079.62   0.8008       5094.66
  15.000     0.6073       98030.37       4515.36   0.7949       5680.24
  15.500     0.6275      104992.00       4997.23   0.7872       6348.00
  16.000     0.6478      112576.31       5531.05   0.7797       7093.68
  16.500     0.6680      120707.19       6115.87   0.7740       7901.46
  17.000     0.6882      129181.81       6743.59   0.7710       8746.97
  17.500     0.7085      137729.56       7401.27   0.7706       9604.01
  18.000     0.7287      146107.69       8075.82   0.7725      10454.11
  18.500     0.7490      154215.06       8760.71   0.7755      11296.42
  19.000     0.7692      162197.37       9463.21   0.7735      12155.68
  19.500     0.7895      170521.37      10210.68   0.7802      13087.20
  20.000     0.8097      179986.12      11053.76   0.7796      14177.99
  20.500     0.8299      191659.50      12064.95   0.7762      15543.65
  21.000     0.8502      206724.00      13330.65   0.7697      17319.16
  21.500     0.8704      226244.75      14935.82   0.7605      19641.54
  22.000     0.8907      250868.19      16949.00   0.7492      22622.29
  22.500     0.9109      280542.37      19389.96   0.7370      26310.78
  23.000     0.9311      314607.50      22219.70   0.7248      30654.70
  23.500     0.9514      350943.06      25324.78   0.7139      35472.14
  24.000     0.9716      387053.87      28524.88   0.7051      40455.93
  24.500     0.9919      420074.31      31603.34   0.6988      45227.64
  25.000     1.0121      447651.25      34365.35   0.6950      49444.45
  25.500     1.0324      468923.75      36718.37   0.6937      52932.97
  26.000     1.0526      485422.50      38755.58   0.6946      55799.49

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE IX

Computer Output Model 4218, L = 600 ft.

```
  9  TEST RUN OF EHP SHP PROGRAM

CB= 0.650   L/B= 7.250    B/H= 2.500    CP= 0.661    CM= 0.983
LBP=  600.00 FT   LWL=  610.12 FT    B=    82.76 FT    H=    33.10 FT
DISP=  30526.83 TONS    VOL=  1068438.00 FT**3    WSURF=  65503.41 FT**2
DELTA CF= 0.0004000    RHO= 1.9904995 LB*SEC**2/FT**4    GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.540 PERCENT OF LBP AFT OF AMIDSHIPS.

 V (KTS)    V/RTLWL       R (LBS)       EHP (HP)     PC          SHP (HP)
 10.000     0.4048       47318.60       1453.02   0.7839         1853.58
 10.500     0.4251       51747.85       1668.49   0.7872         2119.64
 11.000     0.4453       57288.19       1935.08   0.7883         2454.88
 11.500     0.4656       63346.29       2236.97   0.7913         2827.09
 12.000     0.4858       69503.19       2561.10   0.7961         3217.10
 12.500     0.5061       75544.25       2899.70   0.8011         3619.82
 13.000     0.5263       81491.25       3253.09   0.8044         4044.36
 13.500     0.5465       87522.87       3628.24   0.8048         4508.37
 14.000     0.5668       93916.31       4037.48   0.8020         5034.02
 14.500     0.5870      100951.62       4494.92   0.7966         5642.37
 15.000     0.6073      108825.12       5012.58   0.7896         6347.98
 15.500     0.6275      117583.12       5596.52   0.7823         7153.75
 16.000     0.6478      127093.69       6244.32   0.7759         8047.86
 16.500     0.6680      137064.75       6944.66   0.7712         9004.46
 17.000     0.6882      147110.37       7679.50   0.7688         9989.56
 17.500     0.7085      156860.44       8429.32   0.7683        10971.77
 18.000     0.7287      166098.00       9180.75   0.7692        11935.77
 18.500     0.7490      174904.00       9936.02   0.7705        12895.72
 19.000     0.7692      183779.56      10722.39   0.7711        13906.07
 19.500     0.7895      193720.06      11599.79   0.7698        15069.05
 20.000     0.8097      206208.75      12664.21   0.7658        16537.93
 20.500     0.8299      223114.19      14045.01   0.7585        18515.80
 21.000     0.8502      240476.62      15894.11   0.7481        21246.88
 21.500     0.8704      278195.69      18366.65   0.7348        24996.67
 22.000     0.8907      319643.37      21593.82   0.7194        30016.61

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE X

Computer Output Model 4221, L = 600 ft.

```
    9   TEST RUN OF EHP SHP PROGRAM

CB= 0.700    L/B= 7.000    B/H= 2.500    CP= 0.709    CM= 0.987
LBP=  600.00 FT    LWL=  610.12 FT     B=   85.71 FT     H=    34.29 FT
DISP=   35265.23 TONS    VOL=   1234282.00 FT**3    WSURF=   70961.75 FT**2
DELTA CF= 0.0004000    RHO= 1.9904995 LB*SEC**2/FT**4    GNU= 0.128169995E-04 FT**2/SEC
LCB IS 0.550 PERCENT OF LBP AFT OF AMIDSHIPS.

  V (KTS)     V/RTLWL        R (LBS)       EHP (HP)     PC         SHP (HP)
  10.000      0.4048        52995.75       1627.35   0.8240        1974.99
  10.500      0.4251        58169.74       1875.55   0.8276        2266.24
  11.000      0.4453        64292.62       2171.67   0.8271        2625.62
  11.500      0.4656        70977.81       2506.46   0.8231        3045.03
  12.000      0.4858        77922.75       2871.35   0.8173        3513.22
  12.500      0.5061        84933.81       3260.10   0.8112        4018.77
  13.000      0.5263        91980.67       3671.82   0.8060        4555.54
  13.500      0.5465        99147.75       4110.15   0.8022        5123.81
  14.000      0.5668       106616.44       4583.45   0.7996        5731.94
  14.500      0.5870       114609.50       5103.05   0.7980        6394.65
  15.000      0.6073       123332.25       5680.79   0.7968        7129.89
  15.500      0.6275       132919.12       6326.45   0.7953        7954.70
  16.000      0.6478       143397.69       7045.36   0.7933        8881.52
  16.500      0.6680       154681.19       7837.23   0.7904        9915.67
  17.000      0.6882       166596.19       8696.71   0.7867       11055.37
  17.500      0.7085       178947.19       9616.21   0.7822       12294.52
  18.000      0.7287       191616.94      10591.25   0.7771       13629.15
  18.500      0.7490       204693.38      11628.31   0.7717       15068.03
  19.000      0.7692       218605.00      12754.25   0.7662       16645.63
  19.500      0.7895       234246.88      14026.51   0.7608       18437.24
  20.000      0.8097       253066.56      15541.96   0.7555       20573.02
  20.500      0.8299       277086.56      17442.57   0.7502       23249.56
  21.000      0.8502       308829.37      19914.94   0.7448       26738.90
  21.500      0.8704       351123.19      23181.37   0.7382       31400.77
  22.000      0.8907       406778.25      27480.31   0.7285       37721.46

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE XI

Computer Output Model 4213, L = 600 ft.

```
    9  TEST RUN OF EHP SHP PROGRAM

CB= 0.750    L/B= 6.750    B/H= 2.500    CP= 0.757    CM= 0.991
LBP=  600.00 FT    LWL=  610.12 FT    B=    88.89 FT    H=    35.56 FT
DISP=  40634.83 TONS    VOL=  1422218.00 FT**3    WSURF=  76735.56 FT**2
DELTA CF= 0.0004000    RHO= 1.9904995 LB*SEC**2/FT**4    GNU= 0.128169995E-04 FT**2/SEC
LCB IS 1.500 PERCENT OF LBP FWD OF AMIDSHIPS.

  V (KTS)    V/RTLWL        R (LBS)        EHP (HP)     PC          SHP (HP)
  10.000     0.4048         60930.57       1871.01    0.8431        2219.11
  10.500     0.4251         67217.81       2167.28    0.8325        2603.49
  11.000     0.4453         73817.31       2493.40    0.8227        3030.66
  11.500     0.4656         80747.50       2851.47    0.8156        3496.06
  12.000     0.4858         88073.56       3245.40    0.8111        4001.34
  12.500     0.5061         95858.06       3679.42    0.8084        4551.76
  13.000     0.5263        104177.25       4158.70    0.8066        5155.83
  13.500     0.5465        113008.50       4687.23    0.8051        5821.81
  14.000     0.5668        122559.50       5268.85    0.8034        6558.30
  14.500     0.5870        132694.56       5908.29    0.8011        7375.62
  15.000     0.6073        143584.62       6613.63    0.7979        8289.30
  15.500     0.6275        155464.94       7399.55    0.7935        9324.85
  16.000     0.6478        168750.25       8290.97    0.7879       10523.30
  16.500     0.6680        184053.75       9325.70    0.7807       11945.74
  17.000     0.6882        202198.56      10555.24    0.7718       13675.62
  17.500     0.7085        224087.81      12041.96    0.7614       15816.23
  18.000     0.7287        250609.75      13851.97    0.7495       15481.37
  18.500     0.7490        282410.19      16043.28    0.7367       21778.01
  19.000     0.7692        310660.56      18650.21    0.7234       25780.09
  19.500     0.7895        361652.31      21667.42    0.7104       30499.04
  20.000     0.8097        407692.94      25038.27    0.6982       35862.39
  20.500     0.8299        455225.00      28656.37    0.6869       41720.00
  21.000     0.8502        502299.00      32390.80    0.6762       47903.32
  21.500     0.8704        547560.62      36159.28    0.6650       54359.84

*** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE XII

Computer Output Model 4214, L = 600 ft.

```
  9  TEST RUN OF EHP SHP PROGRAM

CB= 0.800   L/B= 6.500   B/H= 2.500   CP= 0.804   CM= 0.995
LBP=  600.00 FT   LWL=  610.12 FT   B=   92.31 FT   H=   36.92 FT
DISP=  46742.03 TONS   VOL=  1635970.00 FT**3   WSURF=  82869.75 FT**2
DELTA CF= 0.0004000   RHO= 1.9904995 LB*SEC**2/FT**4   GNU= 0.128169995E-04 FT**2/SEC
LCB IS 2.500 PERCENT OF LBP FWD OF AMIDSHIPS.

  V (KTS)    V/RILWL      R (LBS)     EHP (HP)    PC        SHP (HP)
   9.000     0.3644      55512.29     1534.17   0.8240     1861.83
   9.500     0.3846      61758.31     1801.61   0.8234     2188.12
  10.000     0.4048      68410.94     2100.90   0.8210     2559.06
  10.500     0.4251      75455.37     2432.88   0.8176     2975.81
  11.000     0.4453      82871.31     2799.23   0.8133     3441.86
  11.500     0.4656      90683.81     3202.35   0.8083     3961.83
  12.000     0.4858      98942.81     3645.91   0.8029     4541.12
  12.500     0.5061     107720.87     4134.76   0.7974     5185.47
  13.000     0.5263     117135.81     4677.79   0.7922     5904.72
  13.500     0.5465     127568.44     5288.32   0.7876     6714.32
  14.000     0.5668     139260.75     5986.64   0.7836     7640.30
  14.500     0.5870     152772.94     6802.29   0.7798     8722.90
  15.000     0.6073     168731.44     7771.92   0.7758    10018.46
  15.500     0.6275     187810.87     8939.09   0.7707    11599.04
  16.000     0.6478     210635.69    10345.67   0.7638    13549.25
  16.500     0.6680     237661.06    12042.58   0.7545    15962.04
  17.000     0.6882     269223.06    14054.34   0.7422    18936.35
  17.500     0.7085     305488.94    16416.28   0.7268    22585.79
  18.000     0.7287     347016.56    19180.68   0.7085    27072.04
  18.500     0.7490     395596.62    22473.23   0.6874    32692.44
  19.000     0.7692     455781.69    26592.64   0.6637    40067.29

 *** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATION OF LCB POSITION ***
```

TABLE XIII

Maximum and Average % Errors in EHP and SHP for 5 Parent Models, L = 600 ft.

Model No.	% Error in EHP		% Error in SHP	
	Max.	Avg.	Max.	Avg.
4210	1.48	.49	1.43	.57
4218	2.12	.74	2.10	.90
4221	2.32	.93	2.25	.99
4213	1.44	.79	1.51	.82
4214	.915	.32	1.13	.34

4218 where the maximum error of 2.74% was experienced in the test of equation (7).

The SCHUYLER OTIS BLAND was also tested without wetted surface as input. The results of this run are presented in Table VII. We can see that the wetted surface calculated by equation (15), 39651.54 square feet, is in error by -.858%. The error in the calculation of wetted surface area tends to reduce the error in EHP in this instance.

One must keep in mind that we are comparing computer output with values derived from hand calculations, in which design charts were read with an unknown accuracy.

2. Test using the five parent models of Series 60 with L = 600 feet

The results of the computer run with the five parent models of Series 60 with L = 600 feet are presented in Tables VIII through XII. In these cases, the wetted surface area of the ships was calculated by equation (15), since it was not known. The maximum and average percent errors in EHP and SHP experienced in this test are presented in Table XIII. Although at some points the errors exceeded 2%, in no case did the average error exceed 1%. These errors are probably due mainly to the innacuracy of the equation used for wetted surface area.

VI. CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of tests run to date, one can conclude that the EHP-SHP computer program presented herein can be relied upon to estimate the EHP-SHP requirements of single-screw merchant ships, falling within the range of hull proportions of the Series 60, to a tolerance in the neighborhood of 1% on the average, and with great certainty, to within a tolerance of less than 3% for any given speed.

The weak link in the EHP-SHP program appears to be the calculation of wetted surface area. It is recommended that the representation of the Series 60 wetted surface contours be further investigated, to determine whether equation (15) can be modified and improved.

It is further recommended that the elements of matrices $[A_{nl}]$ and $[B_{nl}]$ be punched in the form of FORTRAN data statements, and included in the body of the main program. This will greatly facilitate its conversion to a subroutine for inclusion in a larger program if it were so desired.

It is also recommended that the program be extensively tested with existing ships, to further determine its accuracy.

VII. REFERENCES

(1) Todd, F. H., "Series 60 Methodical Experiments With Models of Single-Screw Merchant Ships", David Taylor Model Basin Report 1712, July 1963.

(2) Khoushy, D., "A Method of Estimating EHP From Standard Series Model Testing Results", M.I.T. Department of Naval Architecture and Marine Engineering Report, February 1962.

(3) Pitidis-Poutous, T. M., "The Mathematical Derivation of Preliminary Ship Lines", M.I.T. Department of Naval Architecture and Marine Engineering Report 65-3, February 1965.

(4) Pitidis-Poutous, T. M., "The Computerization of Series 60 Resistance and Propulsion Experiments", M.I.T. Department of Naval Architecture and Marine Engineering Report, May 1967.

(5) Hildebrand, F. B., "Introduction to Numerical Analysis", McGraw-Hill Book Company, 1956.

VIII. APPENDIX

APPENDIX A

PROGRAM LISTINGS

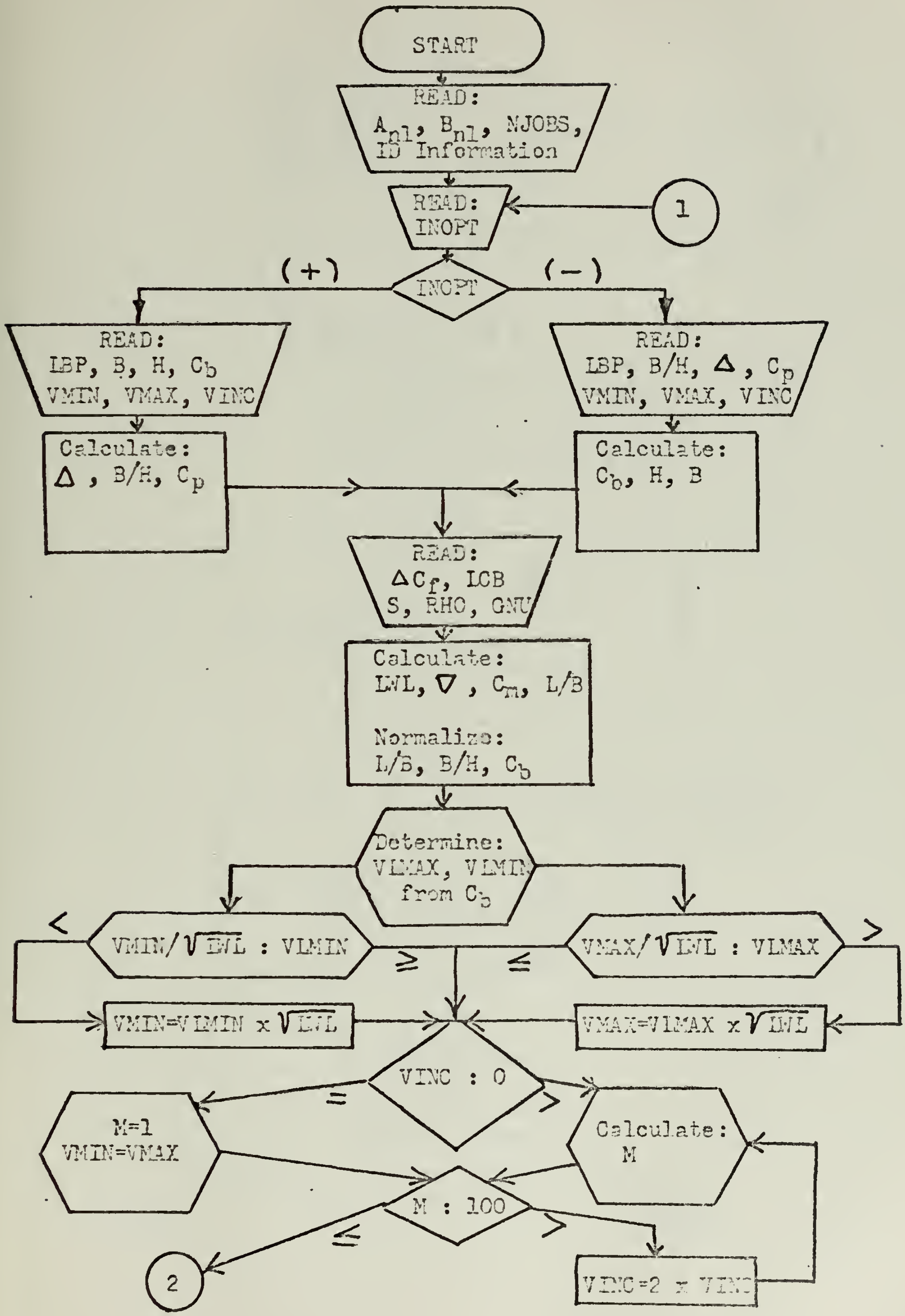
Page

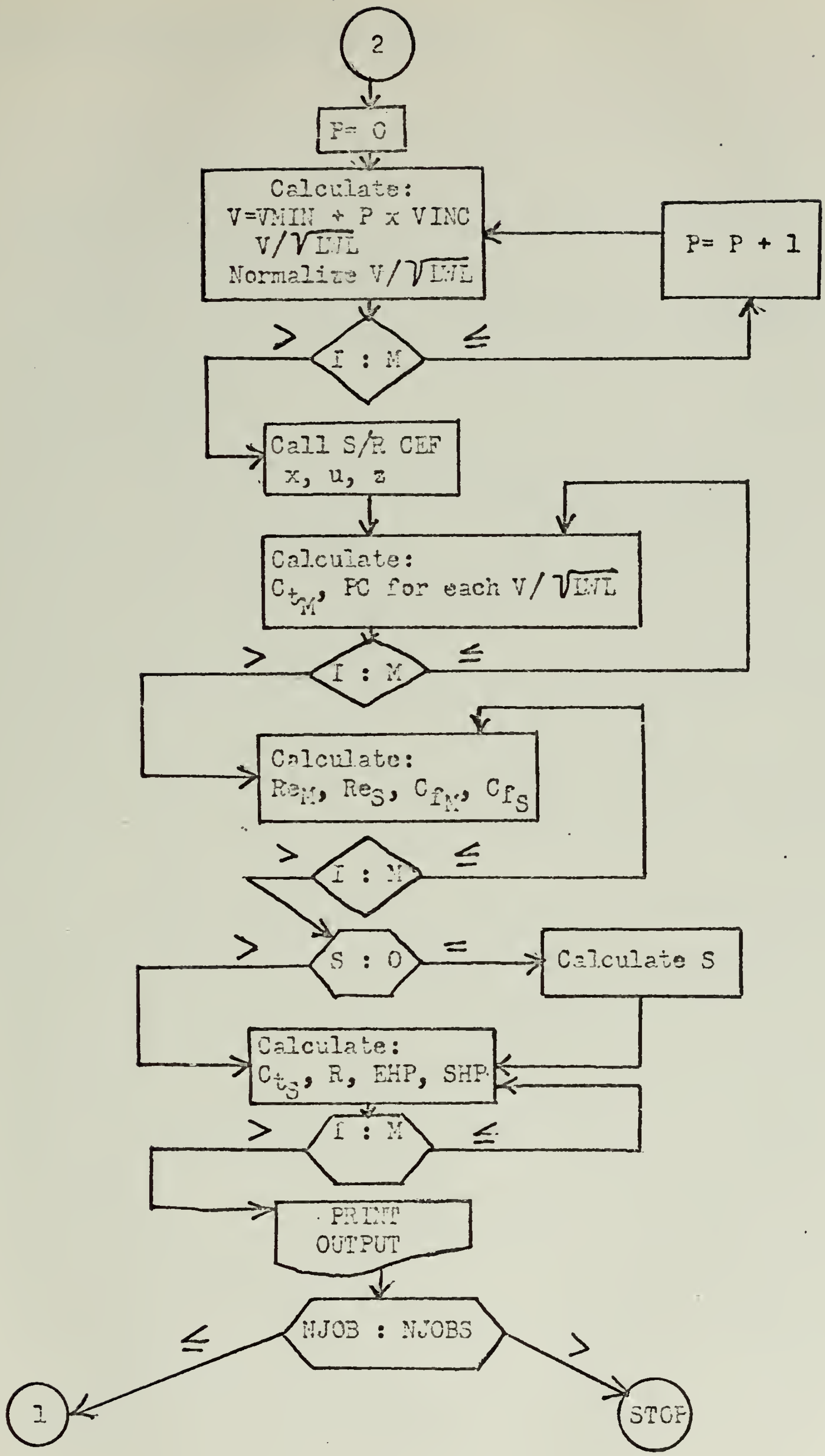
1. Flow chart for EHP-SHP program. 47

2. Listing of EHP-SHP program and S/R CEF. 49

3. Listing of the elements of matrices $\left[A_{nl}\right]$ and $\left[B_{nl}\right]$. 53

1. Flow Chart for EHP-SHP Program.




2
P= 0
Calculate:
V=VMIN + P x VINC
$V/\sqrt{LWL}$
Normalize $V/\sqrt{LWL}$
P= P + 1
>
I : M
≤
Call S/R CEF
x, u, z
Calculate:
C_{t_M}, PC for each $V/\sqrt{LWL}$
>
I : M
≤
Calculate:
Re_M, Re_S, C_{f_M}, C_{f_S}
>
I : M
≤
>
S : 0
=
Calculate S
Calculate:
C_{t_S}, R, EHP, SHP
>
I : M
≤
PRINT
OUTPUT
≤
NJOB : NJOBS
>
1
STOP

2. Listing of EHP-SHP program and S/R CEF

```
C     PROGRAM TO CALC EHP,SHP USING SERIES 60 MODEL TEST RESULTS
      DIMENSION A(10,45),B(10,45)
      DIMENSION VS(100),VL(100),V(100),AVL(10),BVL(10),PHI(10)
      DIMENSION PSI(10),CHI(10),VPHI(10),CTM(100),PCM(100),CFS(100)
      DIMENSION CFM(100),CTS(100),R(100),EHP(100),SHP(100),QQ(20)
    1 FORMAT (5F16.7)
    2 FORMAT (I4,19A4)
    3 FORMAT (7F10.2)
    4 FORMAT (4F10.6,E10.6)
    5 FORMAT (28H SCHOENHER NO CONVERGE.  VS=,F6.3)
    6 FORMAT (4H0CB=, F6.3, 2X, 5H L/B=,F6.3,2X,5H B/H=,F6.3,2X,4H CP=,
     1F6.3,2X,4H CM=,F6.3)
    7 FORMAT (5H LBP=,F8.2,3H FT,2X,5H LWL=,F8.2,3H FT,2X,3H B=,
     1F8.2,3H FT,2X,3H H=,F8.2,3H FT)
    8 FORMAT ( 6H DISP=,F10.2,5H TONS,2X,5H VOL=,F12.2,6H FT**3,2X,
     17H WSURF=,F10.2,6H FT**2)
    9 FORMAT (1H0,2X,7HV (KTS),3X,7HV/RTLWL,6X,7HR (LBS),5X,8HEHP (HP).
     14X,2HPC,7X,3HSHP (HP))
   10 FORMAT (F9.3,F10.4,F14.2,F13.2,F6.4,F13.2)
  500 FORMAT (7H LCB IS,F6.3,33H PERCENT OF LBP AFT OF AMIDSHIPS.)
  501 FORMAT (21H LCB IS AT AMIDSHIPS.)
  502 FORMAT (7H LCB IS,F6.3,33H PERCENT OF LBP FWD OF AMIDSHIPS.)
  503 FORMAT (I4)
  504 FORMAT (1H1,I4,19A4)
  505 FORMAT (10H DELTA CF=,F10.7,2X,5H RHO=,F10.7,16H LB*SEC**2/FT**
     12X, 5H GNU=,E16.9,10H FT**2/SEC)
  506 FORMAT (74H0 *** ABOVE VALUES ARE NOT CORRECTED FOR ANY VARIATI
     1OF LCB POSITION ***)
C     READ COEFF OF POL FOR CTM AND PCM
      DO 200 N=1,10
      READ (5,1) (A(N,L),L=1,45)
  200 CONTINUE
      DO 201 N=1,10
      READ (5,1) (B(N,L),L=1,45)
  201 CONTINUE
C     READ NUMBER OF SHIPS AND ID INFO
      READ (5,2) NJOBS, (QQ(L),L=1,19)
      DO 1000 NJOB=1,NJOBS
C     READ INPUT AND CALC NEEDED PARAMETERS FOR SHIP
      READ (5,503) INOPT
      IF (INOPT) 900,900,901
  900 READ(5,3) XLBP, BH, DEL,CP,VMIN,VMAX,VINC
      CB=.0557*(CP)**2 + .925*CP
      H=SQRT((35.*DEL)/(CB*XLBP*BH))
      BM=BH*H
      GO TO 903
  901 READ(5,3) XLBP, BM, H, CB, VMIN, VMAX, VINC
      DEL=CB*XLBP*BM*H/35.
```

```
      BH=BM/H
      CP=(-.925 + SQRT(.925**2 + 4.*.0375*CB))/(2.*.0375)
  903 READ (5,4)CCF,XLCB,WSURF,RHO,GNU
      XLWL=406.75*XLBP/400.
      VOL=35.*DEL
      CM=CB/CP
      BL=XLBP/BM
C     NORMALIZE PARAMETERS
  600 U=(-7.0 + BL)/1.5
      Z=-6.0 + 2.0*BH
      X=-7.0 + 10.0*CB
C     TRAP TO MAKE SURE VL IS WITHIN RANGE OF MODEL TEST RESULTS
      IF (CB.GE.0.60.AND.CB.LE.0.612) GO TO 800
      IF (CB.GT.0.612.AND.CB.LE.0.625) GO TO 801
      IF (CB.GT.0.625.AND.CB.LE.0.725) GO TO 802
      IF (CB.GT.0.725.AND.CB.LE.0.775) GO TO 803
      IF (CB.GT.0.775.AND.CB.LE.0.800) GO TO 804
  800 VLMIN=.45
      VLMAX=1.1
      GO TO 11
  801 VLMIN=.45
      VLMAX=.90
      GO TO 11
  802 VLMIN=.40
      VLMAX=.90
      GO TO 11
  803 VLMIN=.35
      VLMAX=.875
      GO TO 11
  804 VLMIN=.35
      VLMAX=.80
   11 IF (VMIN/(XLWL**.5)-VLMIN)12,13,13
   12 VMIN=VLMIN*(XLWL**.5)
   13 IF (VLMAX-VMAX/(XLWL**.5))14,15,15
   14 VMAX=VLMAX*(XLWL**.5)
C     CALC OF M. IF VINC=0.,M=1 THROUGHOUT PROGRAM
   15 IF (VINC.GT.0.) GO TO 16
      M=1
      VMIN=VMAX
      GO TO 20
   16 VM=(VMAX-VMIN)/VINC + 0.5
      M=VM
      M=M + 1
C     MAKE SURE M NOT GREATER THAN 100
      IF (M.LE.100) GO TO 20
      VINC=2.0*VINC
      GO TO 15
C     CALC OF SHIPS V, V OVER RT LWL, NORMALIZE V OVER RT LWL
```

```
   20 P=0.0
      DO 30 I=1,M
      VS(I)=VMIN + P*VINC
      VL(I)=VS(I)/(XLWL**.5)
      V(I)=2.5*VL(I)-1.875
      P=P+1.0
   30 CONTINUE
C     CALC OF CT'S AND PC'S FOR 400 FT MODEL
      CALL CEF(5,X,CHI)
      CALL CEF(3,U,PHI)
      CALL CEF(3,Z,PSI)
      DO 32 N=1,10
      AVL(N)=0.0
      BVL(N)=0.0
   32 CONTINUE
      DO 35 K=1,5
      DO 35 I=1,3
      DO 35 J=1,3
      L=J + 3*(I-1) + 9*(K-1)
      DO 35 N=1,10
      AVL(N)=AVL(N)+A(N,L)*PHI(J)*PSI(I)*CHI(K)
      BVL(N)=BVL(N)+B(N,L)*PHI(J)*PSI(I)*CHI(K)
   35 CONTINUE
      DO 40 IM=1,M
      CALL CEF(10,V(IM),VPHI)
      CTM(IM)=0.0
      PCM(IM)=0.0
      DO 36 N=1,10
      CTM(IM)=CTM(IM)+AVL(N)*VPHI(N)
   36 PCM(IM)=PCM(IM)+BVL(N)*VPHI(N)
      CTM(IM)=CTM(IM)*VL(IM)*VL(IM)*0.001
   40 CONTINUE
C     CALC OF CF'S FOR 400 FT MODEL AND OUR SHIP LENGTH
      DO 50 I=1,M
      REM=(VS(I)*1.6889*406.75)/(1.2817E-05)
      RES=(VS(I)*1.6889*XLWL)/(ONU)
      CFM(I)=0.075/(((ALOG(REM)/2.3025851)-2.0)**2)
      CFS(I)=0.075/(((ALOG(RES)/2.3025851)-2.0)**2)
      DO 45 K=1,50
      DUMMY=CFM(I)
      BOGUS=CFS(I)
      CFM(I)=(2.3025851/(4.132*ALOG(REM*CFM(I))))**2
      CFS(I)=(2.3025851/(4.132*ALOG(RES*CFS(I))))**2
      IF(ABS(DUMMY-CFM(I))-5.0E-07)41,41,45
   41 IF(ABS(BOGUS-CFS(I))-5.0E-07)50,50,45
   45 CONTINUE
      WRITE (6,5) VS(I)
   50 CONTINUE
```

```
C     CALC OF WSURF IF NOT GIVEN
      IF (WSURF.GT.0.) GO TO 52
      WSURF=2.654*(BL**.329)*(BH**.206)*(1./CB**.0609)*(VOL**.666)
C     CALC OF OUTPUT
   52 DO 60 I=1,M
      CTS(I)=CTM(I)-CFM(I)-0.0004+CFS(I)+DCF
      R(I)=0.5*RHO*WSURF*((VS(I)*1.6889)**2)*CTS(I)
      EHP(I)=(R(I)*VS(I)*1.6889)/550.
      SHP(I)=EHP(I)/PCM(I)
   60 CONTINUE
      WRITE (6,504) NJOBS, (QQ(L),L=1,19)
      WRITE (6,6) CB,BL,BH,CP,CM
      WRITE (6,7) XLBP,XLWL,BM,H
      WRITE (6,8) DEL, VOL, WSURF
      WRITE (6,505) DCF,RHO,GNU
C     CALC POSIT OF LCB AS PERCENT LBP
      PLCB=ABS(XLCB*100./XLBP)
      IF(XLCB)300,301,302
  300 WRITE (6,500) PLCB
      GO TO 80
  301 WRITE (6,501)
      GO TO 80
  302 WRITE (6,502) PLCB
   80 WRITE (6,9)
      DO 70 I=1,M
      WRITE (6,10) VS(I),VL(I),R(I),EHP(I),PCM(I),SHP(I)
   70 CONTINUE
      WRITE (6,506)
 1000 CONTINUE
      STOP
      END.
```

```
      SUBROUTINE CEF(IQ,U,CEV)
      DIMENSION CEV(10)
      CEV(1)=1.
      CEV(2)=U
      DO 1 I=3,IQ
    1 CEV(I)=2.*U*CEV(I-1)-CEV(I-2)
      RETURN
      END
```

3. Listing of the elements of matrices $\left[A_{nl}\right]$ and $\left[B_{nl}\right]$

```
 14.5496749      .5716764    -8.2847855    -3.8561125    -1.7527813
 -4.2498243     3.6124631     6.9628193     9.5129474     -.1362346
  3.0622852   -10.7471809    -1.9325106    -1.8457452    -1.9138988
  3.4111510     6.6729977     8.6686578    10.9422909    -1.1619693
  5.1626700   -12.7457705     3.8944108   -20.6135871      .2975470
 -3.1337792    -1.5805094    -4.1246761    -4.3190157     9.2565368
  2.6226676     4.1792587     2.9804134    -3.7988752    -7.7339188
 -9.5670892   -18.9723346    -2.0663788     1.4384205    17.0297606
  -.1651251    26.2876034    -3.7946664    -5.4386603    -8.5539843
  2.0543374     6.0696033   -14.7957796    -8.0446357    -5.2953234
 -9.6466057     6.6879889    15.2288588    19.5549841     3.3218863
 10.0803037   -18.7150843    -5.4674808    -8.7203598    -4.4610978
  7.4975004    16.6380384    19.5020454    21.5180669     1.3053365
 11.7528948   -25.7646174     4.4902981   -41.6621118      .4519087
 -1.9336088     -.7903183    -4.0614309    -6.6258063    19.3319943
  3.2480401     5.8423042     4.0355520    -6.4192246   -12.6607876
-16.1050329   -36.8042016    -1.8150560     3.9613633    31.8206713
 -1.4036943    50.2369723    -6.9833475    -8.3405252   -15.8904130
 15.6760455    10.4243429   -10.1061479    -8.8934225    -9.5402666
 -9.6399064     6.2720277    17.9089139    20.2862217     6.1209267
 21.5296779    -9.4334426    -9.5180357   -16.4130535    -9.0837952
  6.9852836    25.4480231    24.0250919    27.9649415     8.6855114
 15.5010594   -26.4746642    -3.9946576   -40.3662152     1.8919065
  6.7128025     5.8870946      .3066370      .2028761    21.0287769
  -.5120574      .0038713      .3865842    -4.5718835    -3.4520131
 -9.9060216   -29.2158365     1.1079659     5.6389875    24.9728816
 -3.3926241    41.8341432    -4.8893459    -3.6825050   -11.5304912
  9.6277839    16.2365427    -4.7057711    -9.1724963   -12.4285052
-10.1977649     4.9444501    19.3510261    19.8452249    14.4467354
 30.3299296    -1.1930575   -12.6853125   -24.2127221   -10.9986560
  6.9635317    31.6147134    27.1034150    29.7396600    16.3621583
 18.0186410   -25.0731938   -11.5984603   -37.1239061     2.1597570
 15.6393522    11.2933784     8.2181656     5.6847672    21.3774393
 -4.9929367    -5.4918893    -3.9628538    -1.7890584     4.8907150
 -2.2783773   -22.1802971     5.0908844     7.1318989    16.8954766
```

```
-5.3170545    31.9314883    -2.6228630     2.2978479    -6.7321571
11.8046221    16.8483317    -1.3616961    -8.0307753   -12.9745721
-8.0623987     3.7068108    17.5423138    16.8846807    15.0283954
33.0343471     4.3873239   -13.0649903   -24.7953579   -11.6603972
 5.3567724    31.9054513    25.5359321    30.3489339    18.1544290
16.9426033   -21.3634393   -14.9297326   -30.0821266     2.7397027
18.8139179    14.2128931    10.4517806     9.0564336    18.7859466
-6.9630762    -8.2956539    -5.7272328     -.1419604    10.5126357
 2.3896891   -13.4521494     6.2375143     7.1761674     9.1655771
-5.5363443    21.1195140     -.6466088     5.3161080    -2.7937962
 7.6491293    13.9565181      .3390148    -5.9243636    -9.7889333
-5.9891410     2.1740156    12.9872986    12.2557778    13.8835579
26.4788816     4.7188652   -10.3004735   -20.0587032    -8.1084230
 3.9316863    24.9271210    19.5834780    23.1302602    15.4776404
12.8033336   -15.1794297   -12.9500010   -21.2708123     1.9024716
16.5526330    11.9899117    11.2554277     7.8358411    13.8824370
-6.9536052    -7.4361722    -5.8352085      .9578657    10.4258676
 4.4426124    -8.2991840     5.9466958     5.5967175     4.0256317
-4.5155461    13.0371617      .4170871     6.2461205     -.4626160
 4.9686791     8.6509578      .2686214    -3.3365207    -5.9321306
-2.8857442     1.1369262     7.5211015     7.1035506     7.4280680
17.1709690     3.2091572    -6.2114894   -11.8777188    -4.8145428
 2.0169939    15.3641480    11.9175990    15.3347312     9.5342816
 7.4719890    -8.9593991    -8.3577209   -12.3337072     1.3293714
10.6678203     8.1875609     7.5991908     5.2796269     8.1964577
-4.8612539    -4.9861941    -3.8979355      .8635454     7.7172657
 3.4956292    -3.7062310     3.8165946     3.4439623     1.0522689
-2.7007209     6.6725984      .7108781     4.5104439      .3161128


 1.8698787     4.1853800      .1487274    -1.4806088    -2.4141309
-1.3599608      .3849398     3.2194672     3.2861004     3.5065768
 8.0321795     1.1042810    -2.7129406    -5.4433204    -1.5610843
  .9066764     7.0042307     5.4522433     7.2624248     4.5968636
 3.2530742    -4.0148737    -3.9639859    -5.8328272      .4449681
 5.1658454     3.8165532     4.6500745     2.2620510     3.7979926
-2.7570346    -2.3180079    -2.2647659      .6140505     3.8909949
 2.1204210    -1.9672355     2.0035094     1.5157595      .0777516
-1.2868009     3.2611810      .5318359     2.6815342      .3713358
```

```
 .6317063    1.2919876   -.0614546   -.3943637   -.7158684
-.2238261     .1009914    .9291503   1.0207273    .6062516
2.7640227     .1930576   -.8110600  -1.5137119   -.4134494
 .2020339    2.2247532   1.7596720   2.7374516   1.3432676
 .9466791   -1.3162949  -1.2800668  -1.9916549    .1605352
1.6722767    1.3877910   1.6617658    .7139192   1.2068615
-1.0138914   -.8003770   -.7665300    .2162399   1.4866735
 .7438036    -.5834124    .6620204    .4691336   -.1558392
-.3716514    1.0945180    .2508349    .9909297    .1530140
 .0595172     .2578350    .0155676   -.0807562   -.0264893
-.1076959     .0035852    .0877803    .2221843    .1107132
 .4579571    -.0435932   -.0877597   -.2452759    .1088370
 .0257313     .3892129    .2623063    .5089674    .2720818
 .1193083    -.2068912   -.2309001   -.4405312   -.0214911
 .2874346     .1844823    .4975139    .0289373    .2555876
-.2742635    -.0980271   -.2669222    .0689909    .2763594
 .2169974    -.3020333    .1725841    .0330133   -.0344202
-.0965055     .3777790    .0780696    .3087687    .0584769
 .2541038     .4232967    .0767439    .1033556   -.5678897
 .7987619    1.0533708    .3139602    .5438935   -.0938585
 .9878004     .5471122    .1808243   -.2561980    .7543287
1.9480702     .9869102   1.2266403    .5290113    .4983636
-.3784830     .9161593    .0801562   1.5257091   1.1486063
1.1457925     .6738259    .7930704    .5889751    .6864411
 .2257404     .2943734   -.1804690    .7857257   1.2769962
 .6674957     .5787748    .7219169   1.3900262   -.3900655
-.0823217   -1.1923424    .5723766    .7177579    .6897469
-1.0719834    .9188903   -.2299209   -.0254478   -.5325940
1.1443952    1.9209181    .5186395   1.3433188    .0203828
1.4899997    1.1614208    .6623049  -1.4928314   1.9979573
3.1552848    1.4906462   1.5940904   1.0182827    .7293936
-.6929912    1.4401117    .7414124   2.3014983   1.7849107
2.0873592     .9807466   1.2909711   1.1519414    .6958462
 .4851619     .4529909   -.0444665   1.4314161   2.2627113
1.5785205    1.3146395    .9956002   2.9576373   -.7126732
-.1463156   -2.5368023    .8150229   1.3667119    .8183961
-.6352645     .3808876   -.0352766    .1244402  -1.0131074
1.2090834    1.0037405    .0483412    .4136766   -.0070176
 .7654355     .3941625    .0799502   -.3910394    .8957470
1.6873821     .7706689   1.0262161    .7978415    .1869531
```

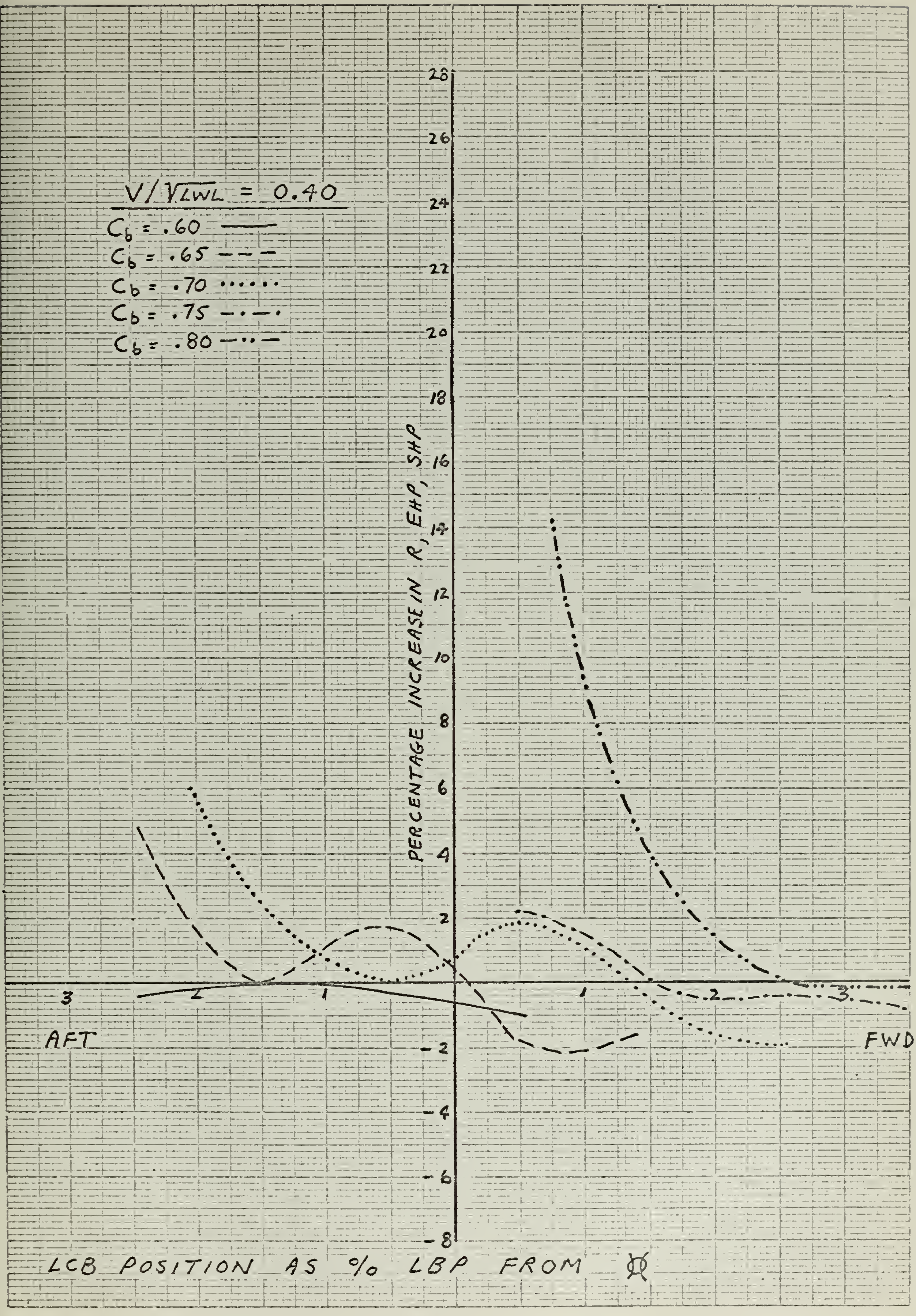
```
 -1.0174062      1.2272588       .0277420      2.2248897       .6622314
 1.2343022       .3191111      1.2313373       .2914792       .6947060
  .2556209       .5969617      -.5552304       .4701235      1.7656431
  .6015071       .9678315       .5887362      1.9449540      -.5314181
  .0696292     -2.0758149       .5709173      1.0927017       .9293203
 -.5433651       .0979775      -.4586072      -.1679318      -.3841697
  .5995327       .2387508      -.3154302       .2309270       .1913938
 -.3164427       .1301091       .1871417     -1.0789750       .9485394
 -.1030191      -.2956169      -.3943946       .5244963      -.4128682
-1.0915548       .5134319       .3548732      1.0662324      -.6020940
  .4450613      -.4476712       .7233817      -.2412496      -.2129788
  .1716482       .4584015      -.3765060      -.2220825      1.0245646
  .3836390       .9218967      -.2218696      1.5729171      -.3337805
  .2509693     -1.8923499      -.0188731       .7975764       .1627162


 -.2318116      -.2726382      -.2250979      -.0597742      -.6425973
  .5356344      -.4447516      -.6417488      -.4441709       .0796384
 -.7687533      -.3785159      -.2327542      -.1812488       .0687391
-1.1483278      -.8185137      -.7978703       .2427631      -.7178155
-1.0971849       .2720826      -.1814688       .8221986     -1.3255902
 -.2798935      -.8826237       .5132478      -.8240440      -.2302237
 -.0121929       .4837445      -.6689419      -.8747298       .4838448
 -.3730438       .5433489      -.5471104       .5888725      -.1386250
  .4040951     -1.3120895      -.2039831       .4822506       .1838319
 -.1914066      -.2330157      -.3476290      -.1605618      -.1694998
  .1840011      -.5599873      -.6129426      -.3196826       .1466315
 -.9493364      -.2697778      -.0688175      -.4867885       .1795903
-1.4804842     -1.0588940     -1.1611848       .0495641      -.7078288
 -.8066642      -.0784238       .0271390       .1701530     -1.4417000
 -.4933256      -.9517099       .1416311      -.8027830      -.5760616
 -.0270473       .3197329      -.3942372      -.8647953       .1014275
 -.2766065       .4118123      -.7883457       .3610556      -.0280498
  .3881132      -.9727482      -.3786107       .2734010      -.2005255
 -.0486688      -.2215381      -.1073853      -.0491817      -.2416412
  .1666388      -.4835957      -.4904987      -.3828980       .0474045
 -.6489097      -.2746769      -.1604075      -.0117688      -.1063150
-1.1093966      -.7749705      -.7614009      -.0470969      -.4841899
 -.5111476      -.0602084      -.1597147       .1598024     -1.0513411
```

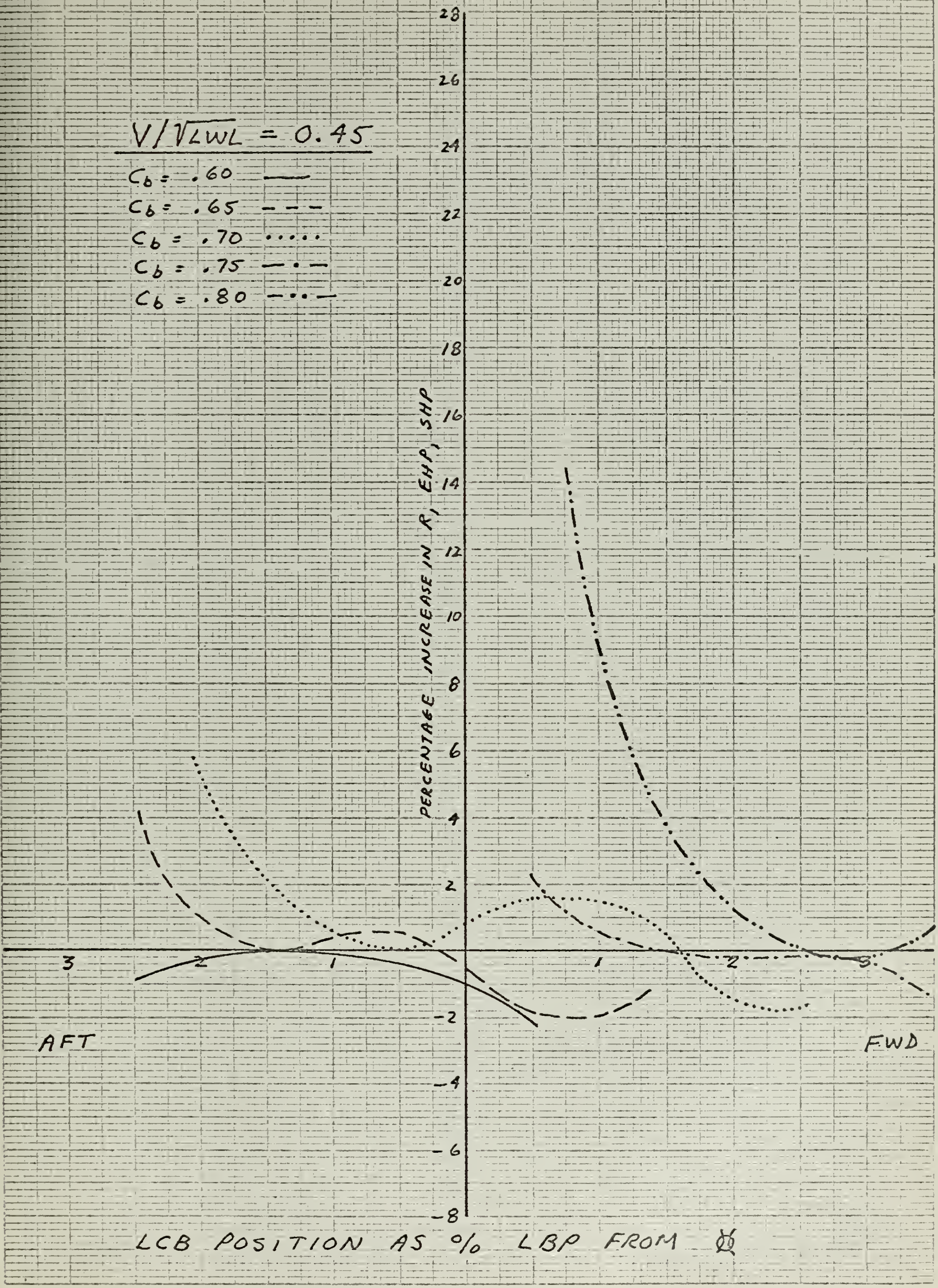
```
-.4893074    -.6992539     .0503937    -.6744570    -.3157174
-.0603174     .2381461    -.3582849    -.7025383    -.0198854
-.3919283     .1651889    -.5856972    -.0308532     .0264681
 .3309325    -.5212609    -.2487222     .1319267    -.0511100
-.0509913    -.0689196    -.1021630    -.0482668    -.0185932
 .0554376    -.2413784    -.2571989    -.1376140     .0573766
-.3685415    -.0669547    -.0234118    -.1049349     .0323723
-.6209035    -.4851913    -.4903417    -.0628357    -.2327750
-.2192922    -.0785230    -.0264358     .0064128    -.5756791
-.2806189    -.3999087    -.0542858    -.3525030    -.2659979
-.0285604     .1278625    -.1355842    -.3443935    -.0478000
-.1393590     .0934717    -.3946693    -.0007085     .0291116
 .1817481    -.2881980    -.1653813     .0641398    -.1124139
-.0061540    -.0249686    -.0048420     .0013265    -.0401150
 .0428432    -.0936094    -.1152594    -.0764807     .0105730
-.1125915    -.0292852    -.0272779     .0296546    -.0177826
-.2252641    -.1831350    -.1635496    -.0392735    -.0693002
-.0702668    -.0184580    -.0406982     .0341093    -.2122658
-.1295756    -.1557337    -.0287787    -.1532894    -.0781477
-.0150641     .0492547    -.0655933    -.1406032    -.0190101
-.0881553     .0136718    -.1586125    -.0490134     .0105931
 .0932999    -.1000036    -.0483666     .0249204    -.0093009
-.0079566     .0067028    -.0119163    -.0007928     .0075951
 .0136688    -.0126482    -.0189720    -.0022155     .0095868
-.0284385     .0120257     .0055343    -.0025614     .0089682
-.0494890    -.0555365    -.0458509    -.0137878    -.0046506
-.0087769    -.0044427    -.0042037     .0086206    -.0475444
-.0242116    -.0408702    -.0166316    -.0328551    -.0331722
-.0072865     .0205311    -.0094810    -.0207007    -.0044426
-.0004944     .0054106    -.0484847    -.0031020     .0037651
 .0152624    -.0331273    -.0169808     .0093473    -.0149762
```

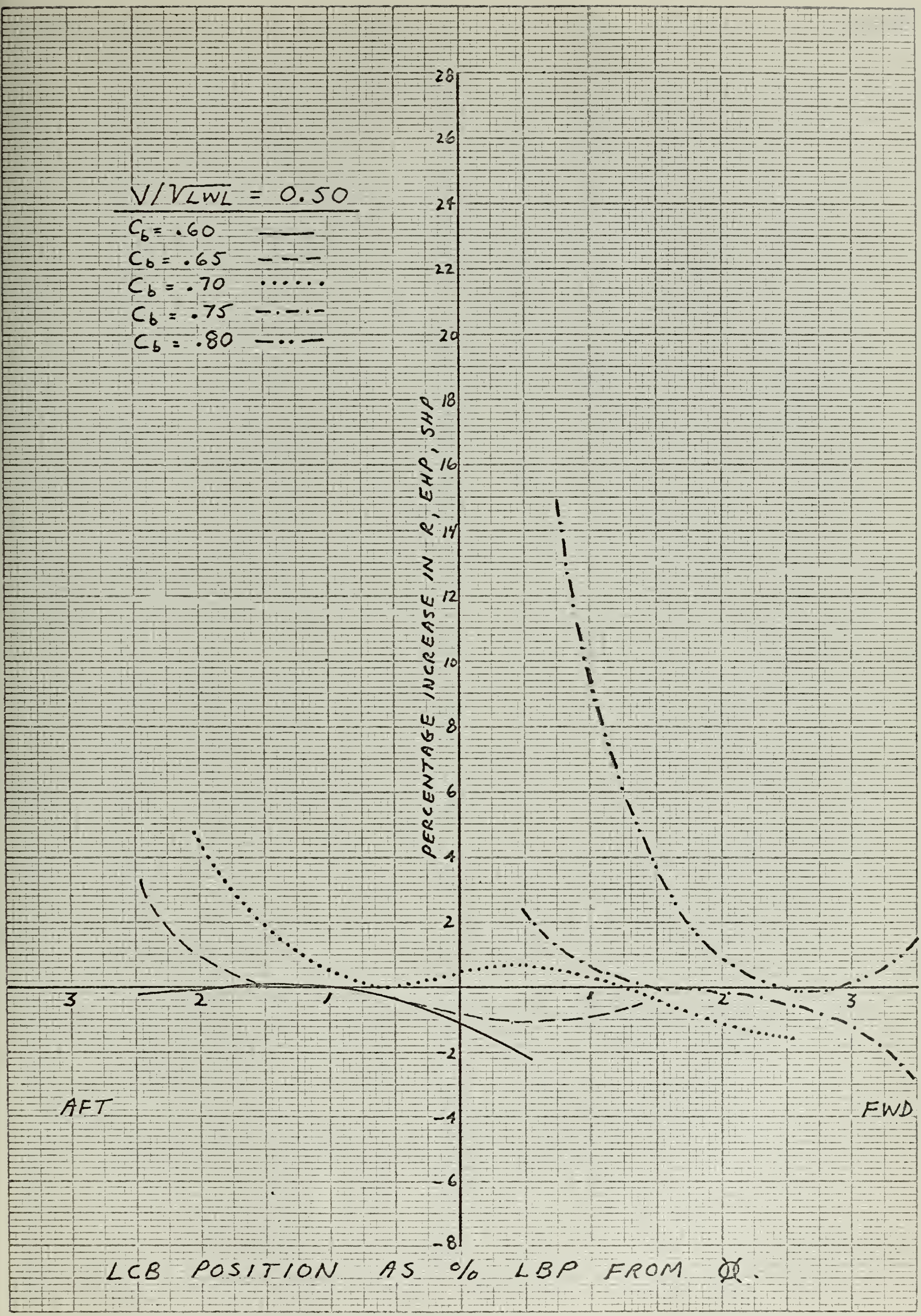
APPENDIX B

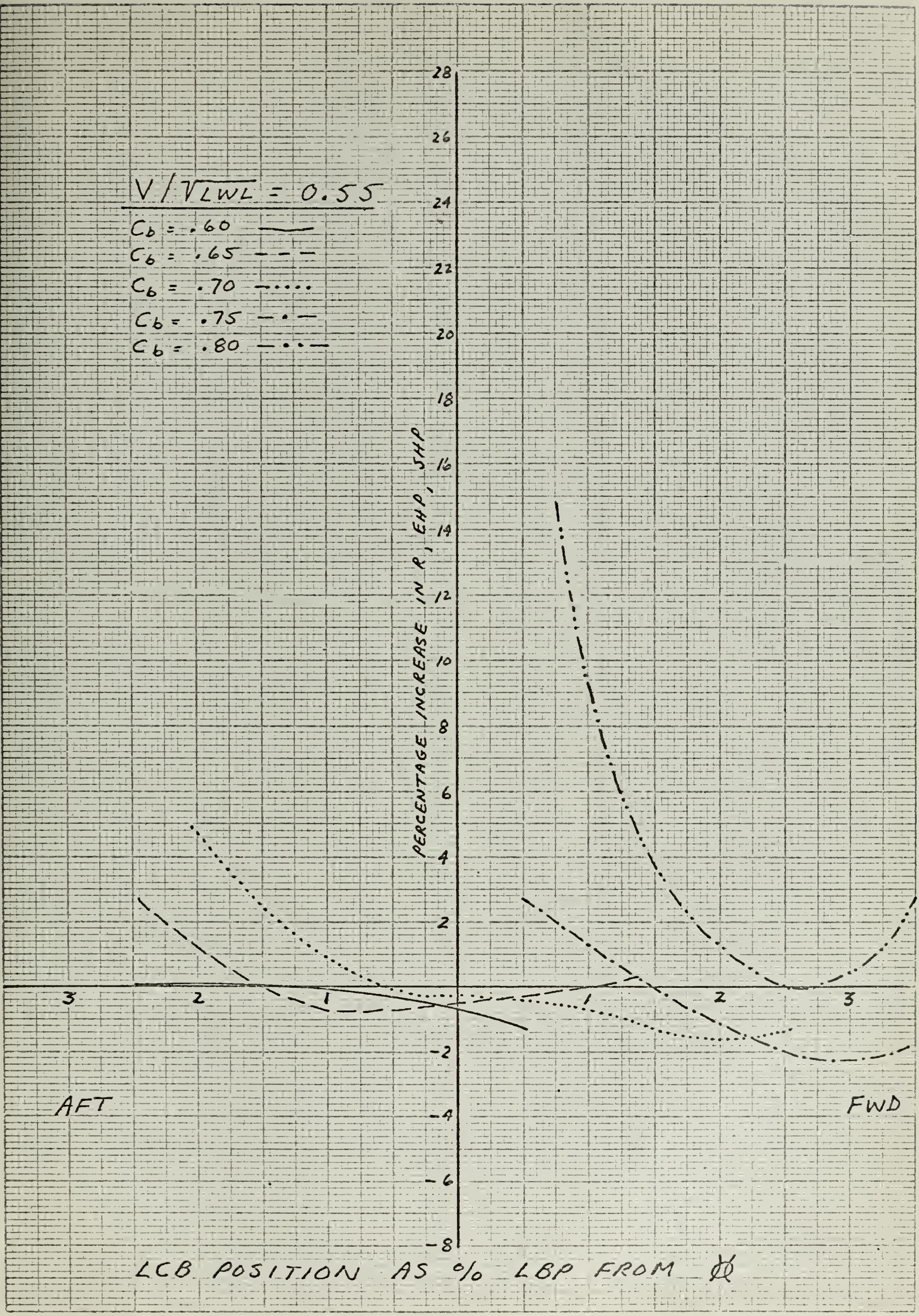
GRAPHS FOR USE IN CORRECTION OF EHP AND SHP FOR VARIATION IN LCB POSITION

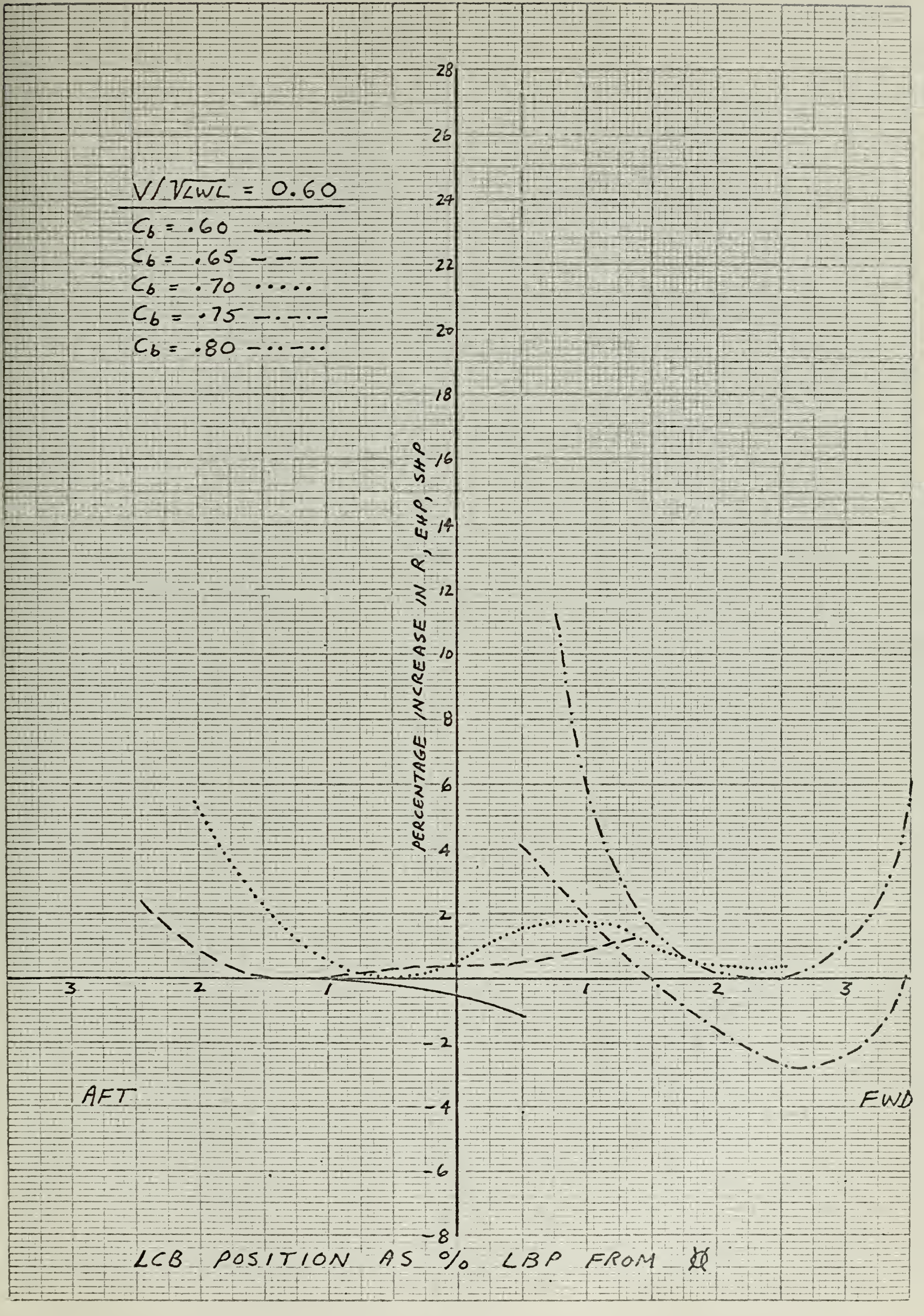


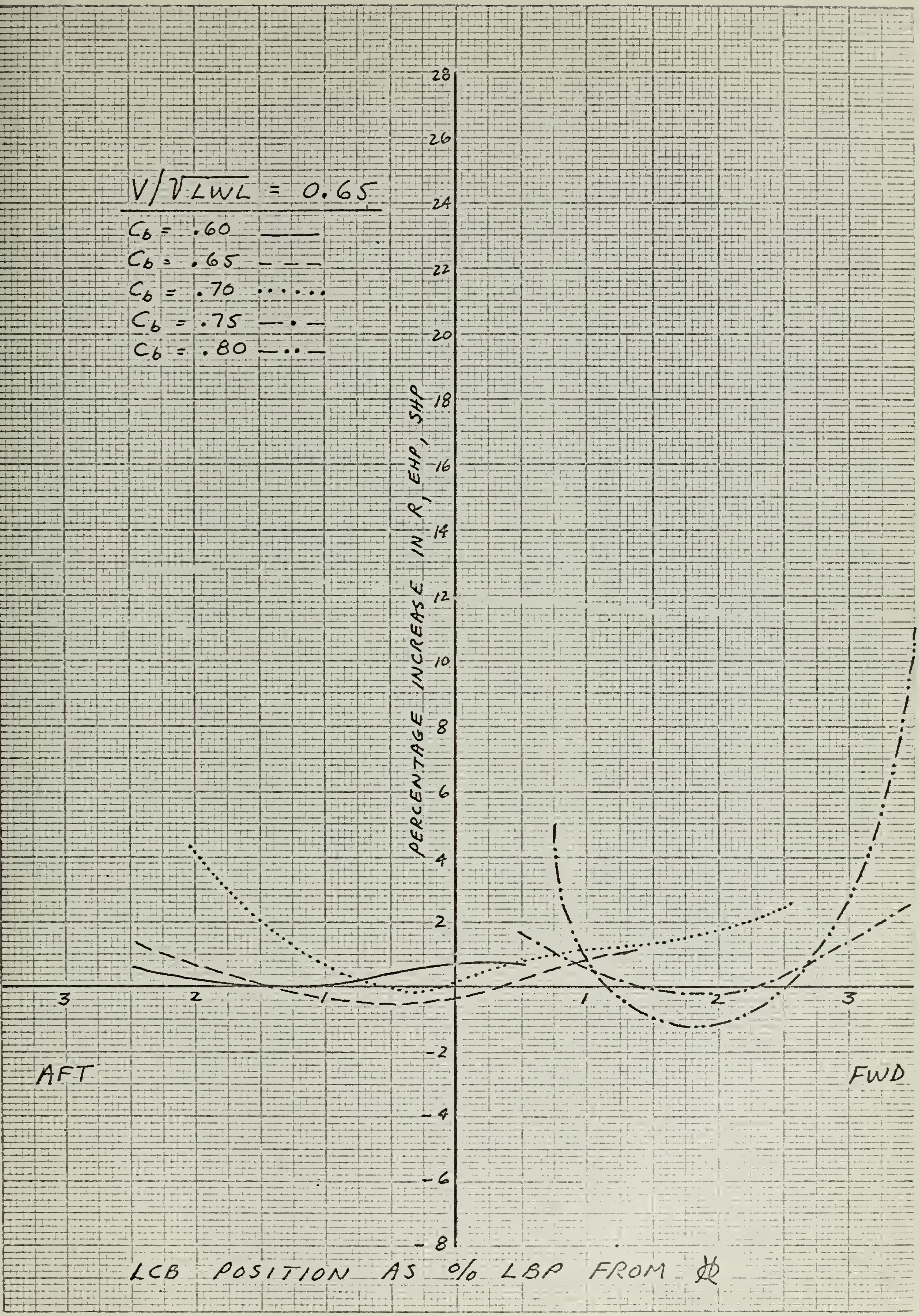
V/√LWL = 0.40
Cb = .60 ——
Cb = .65 – – –
Cb = .70 ……
Cb = .75 –·–·
Cb = .80 –··–
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
PERCENTAGE INCREASE IN R, EHP, SHP
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

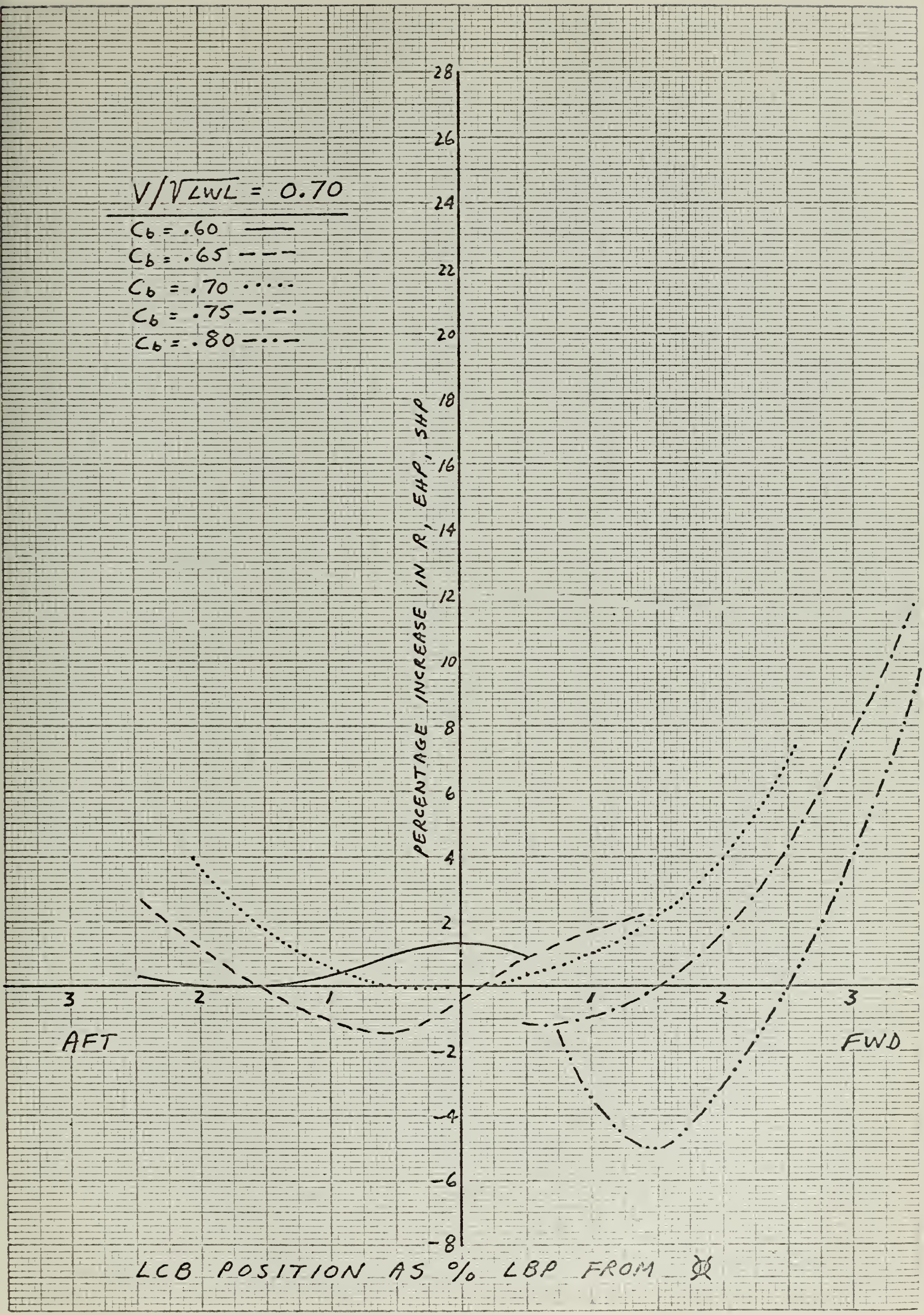

V/√LWL = 0.45
Cb = .60 ——
Cb = .65 - - -
Cb = .70 ·····
Cb = .75 —·—
Cb = .80 —··—
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
PERCENTAGE INCREASE IN R, EHP, SHP
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊄

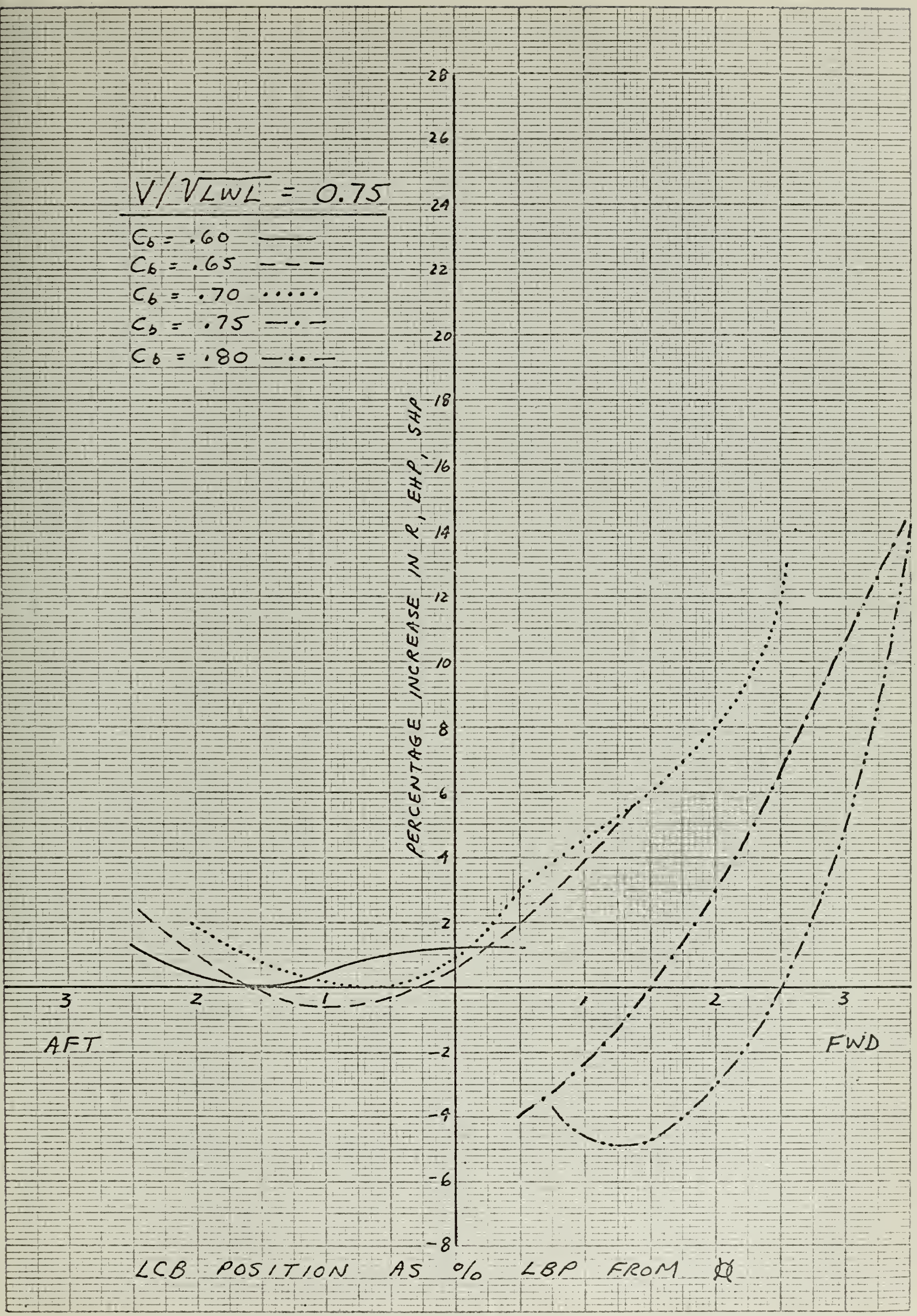

V/V_LWL = 0.50
C_b = .60 ——
C_b = .65 – – –
C_b = .70 ⋯⋯
C_b = .75 –·–·–
C_b = .80 –··–
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
PERCENTAGE INCREASE IN R, EHP, SHP
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗.

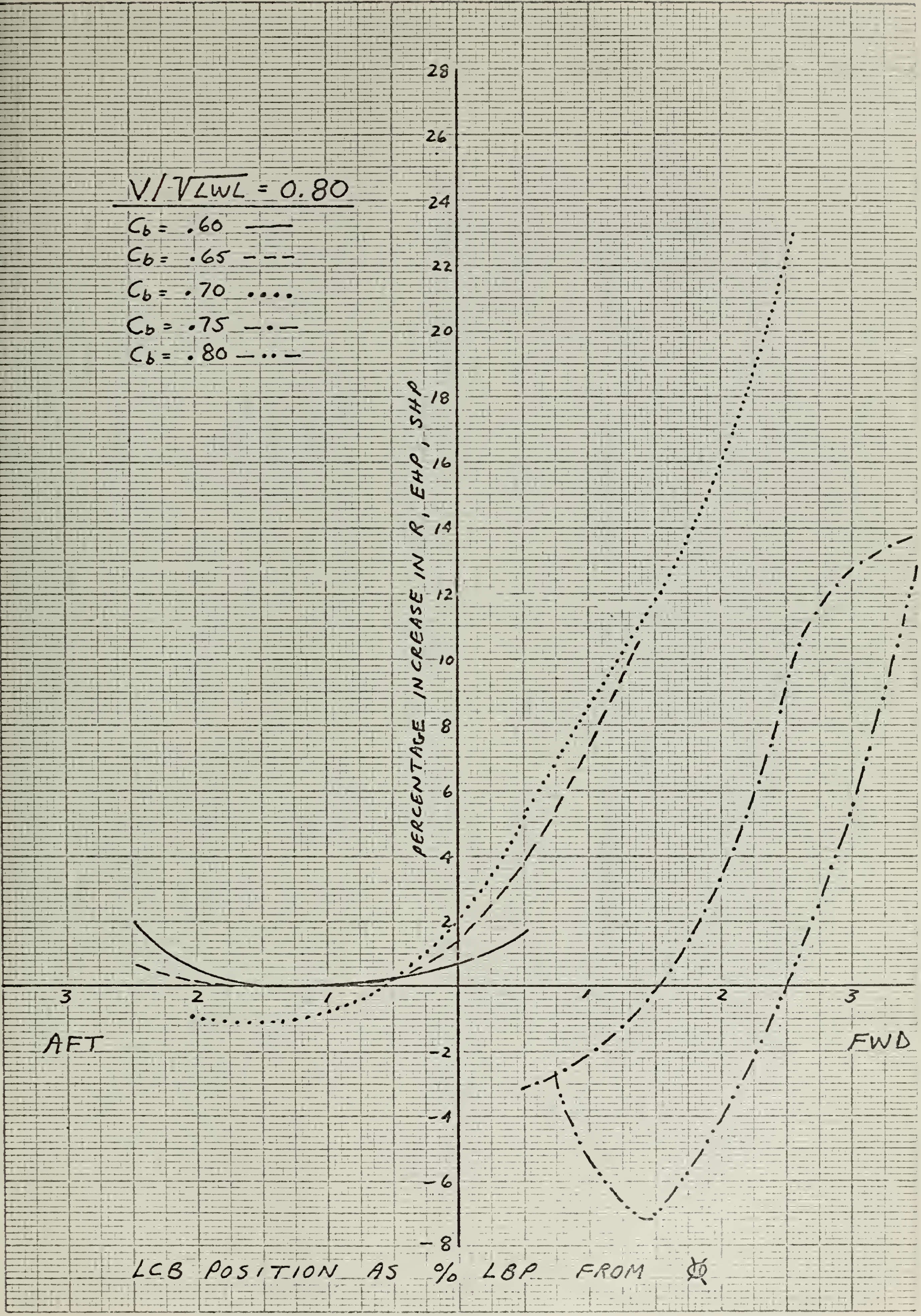

V/√LWL = 0.55
Cb = .60 ——
Cb = .65 – – –
Cb = .70 –·····
Cb = .75 –·–
Cb = .80 –··–
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⩛

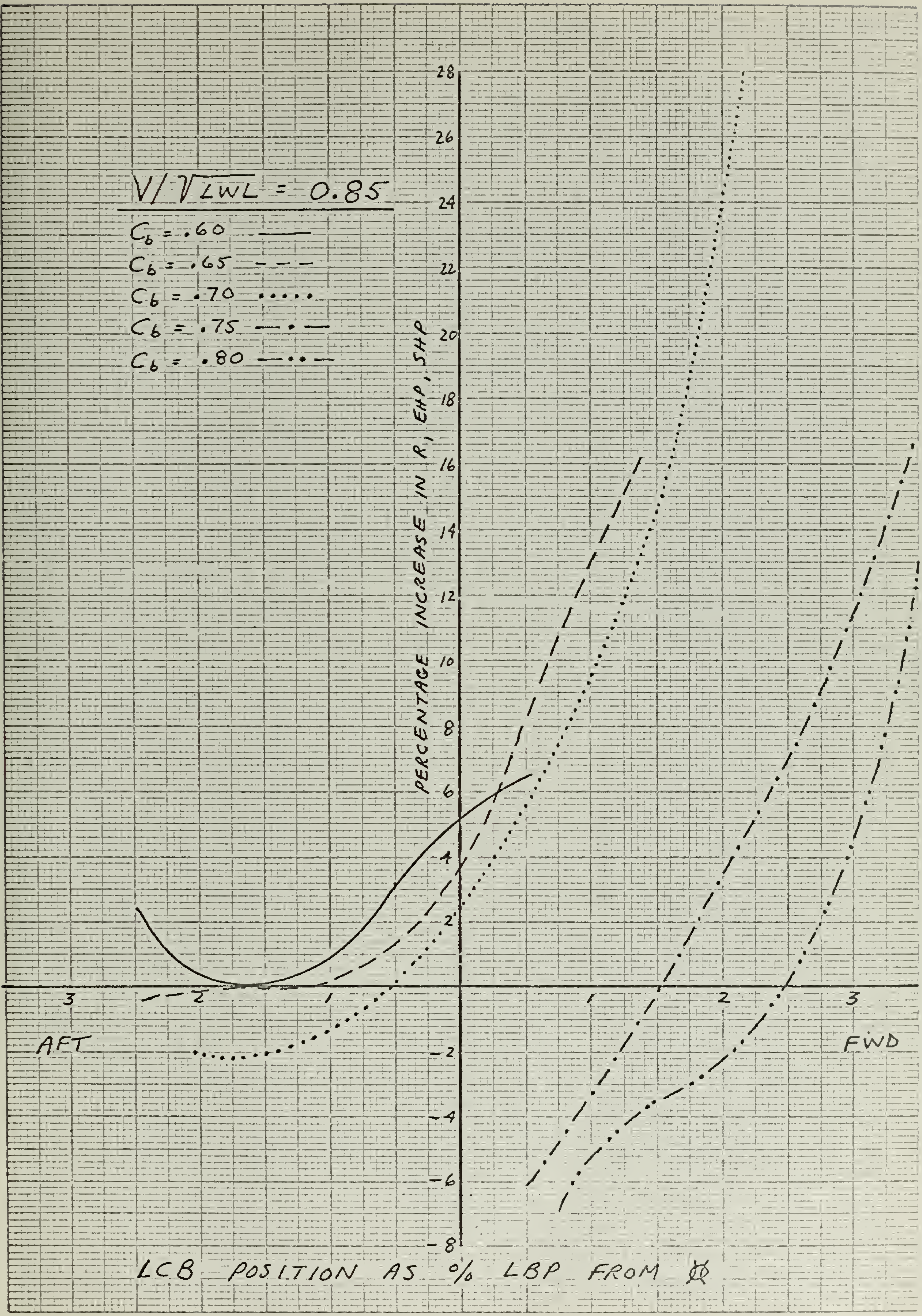

V/√LWL = 0.60
Cb = .60 ——
Cb = .65 — — —
Cb = .70 ·····
Cb = .75 —·—·—
Cb = .80 —··—··
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

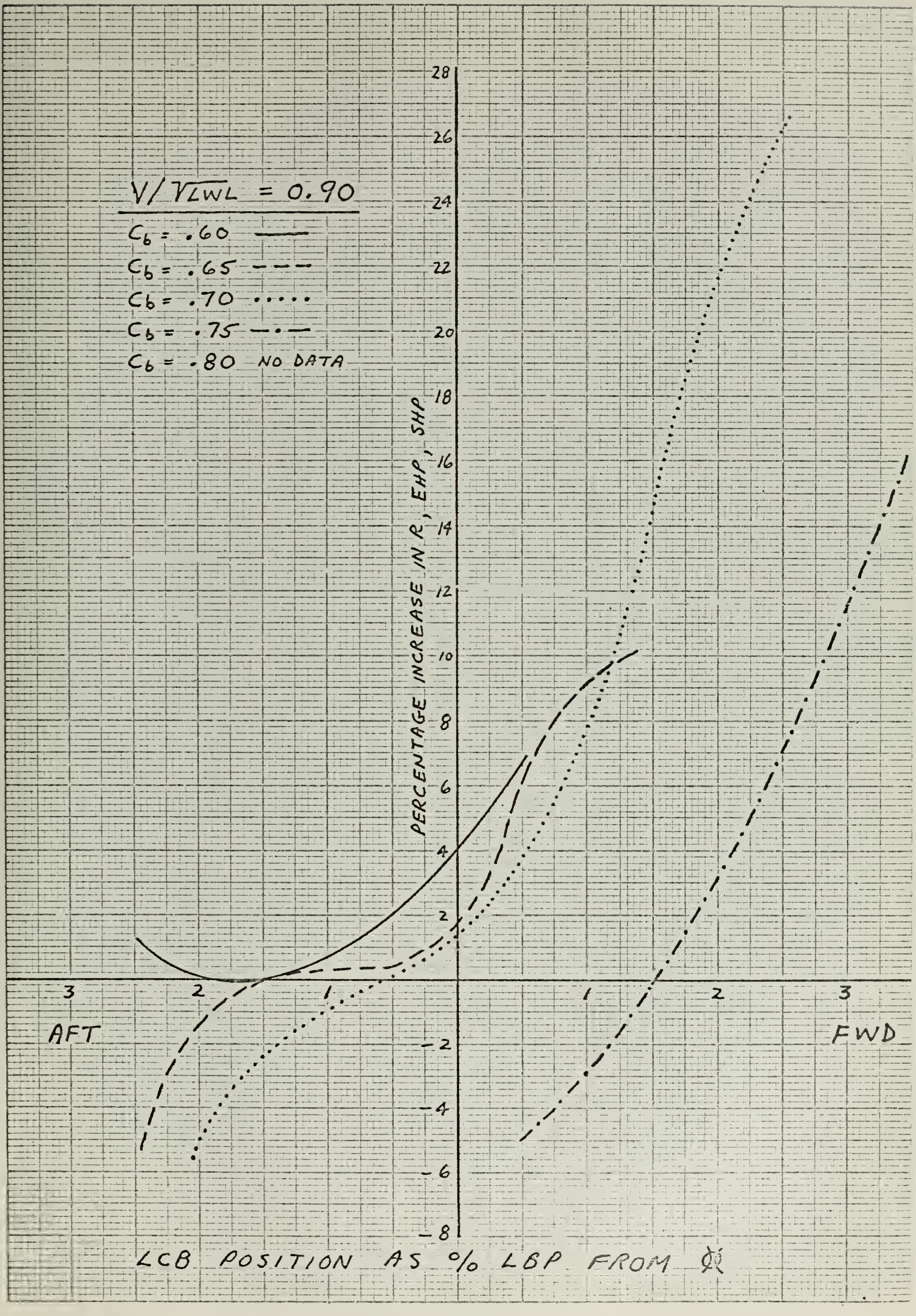

$V/\sqrt{LWL} = 0.65$
C_b = .60 ——
C_b = .65 – – –
C_b = .70 ......
C_b = .75 —•—
C_b = .80 —••—
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊕

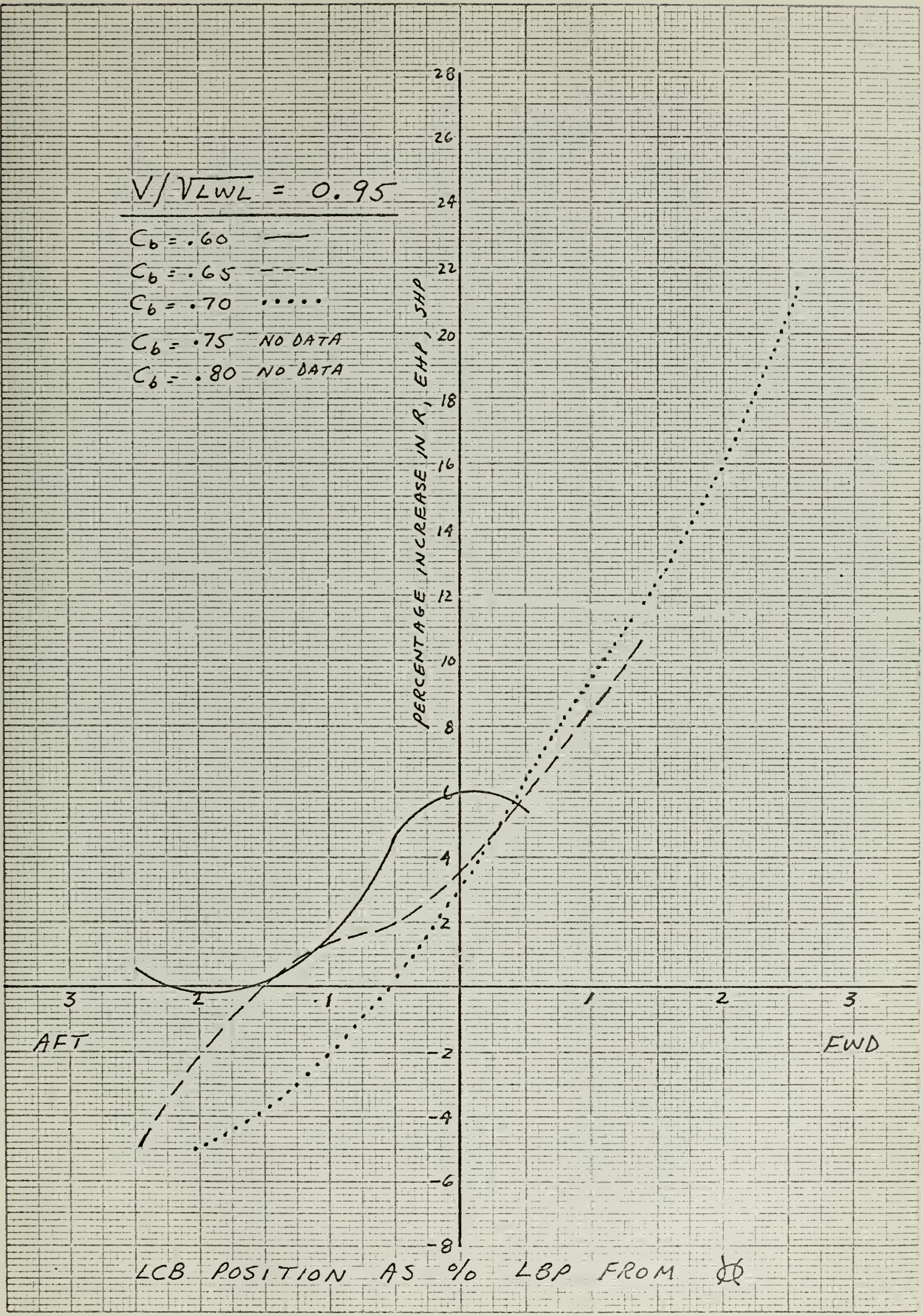

V/√LWL = 0.70
Cb = .60 ——
Cb = .65 – – –
Cb = .70 ·····
Cb = .75 –·–·
Cb = .80 –··–
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⨂

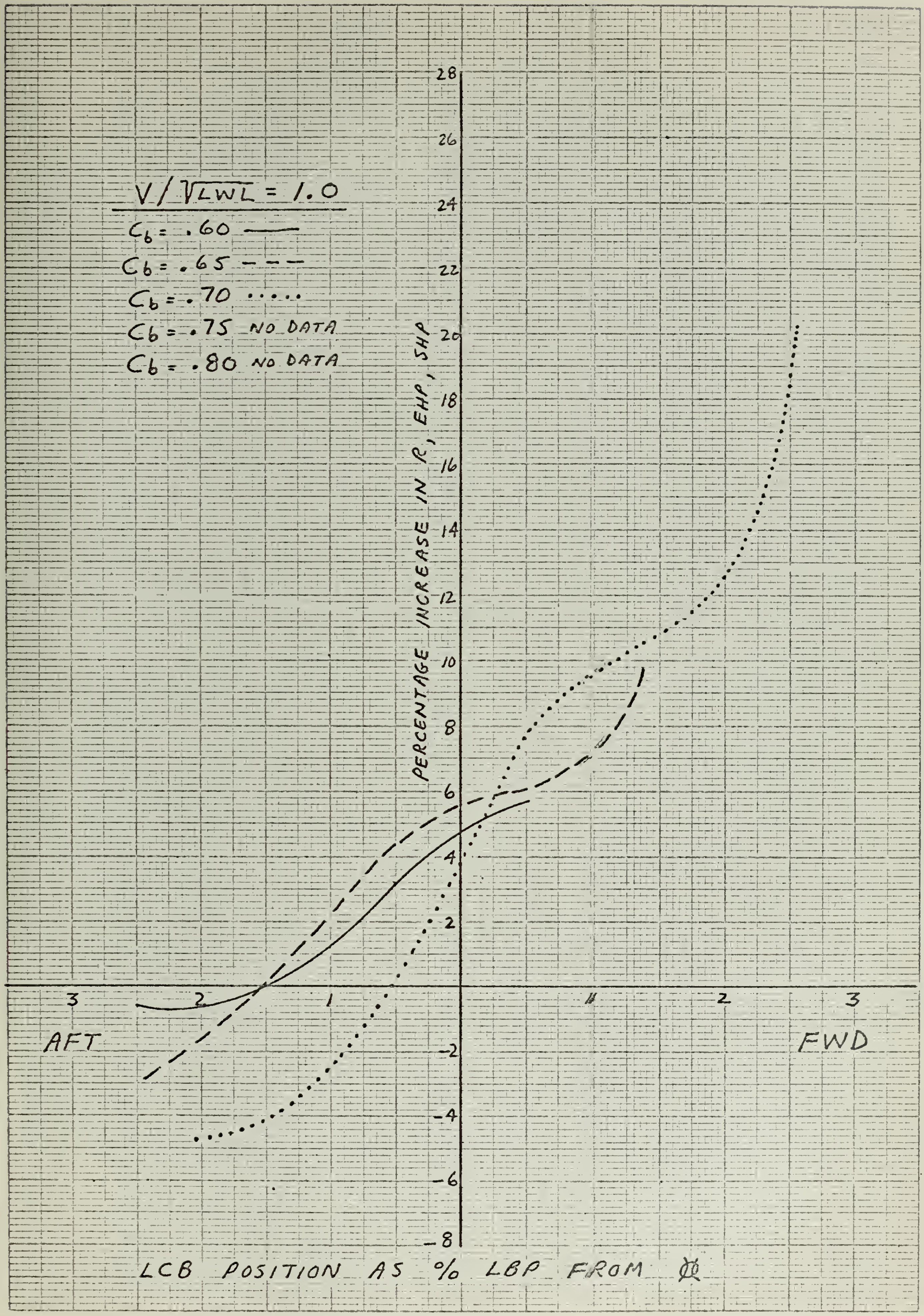

V/√LWL = 0.75
Cb = .60 ———
Cb = .65 — — —
Cb = .70 ·····
Cb = .75 —·—
Cb = .80 —··—
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

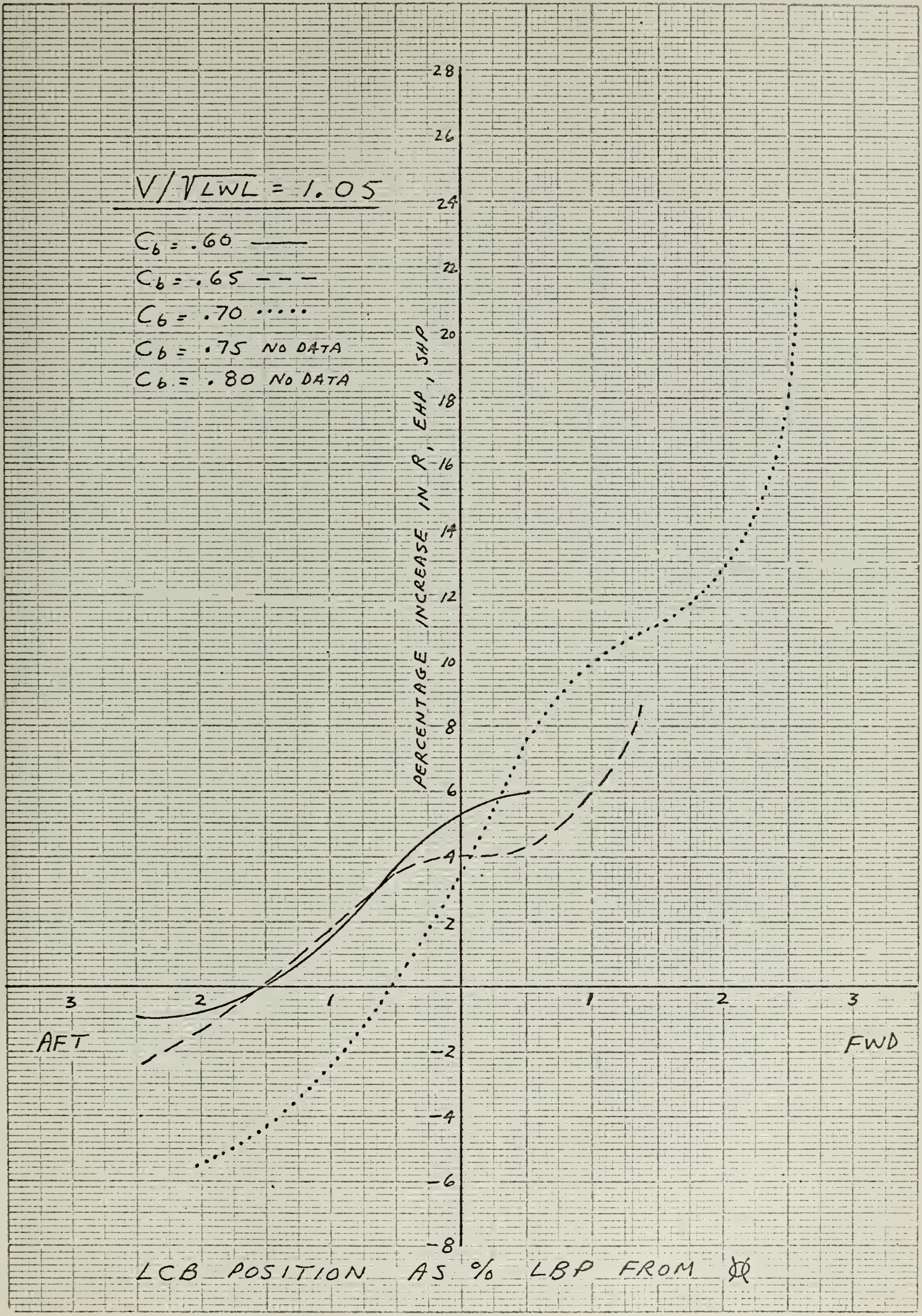

V/√LWL = 0.80
Cb = .60 ——
Cb = .65 – – –
Cb = .70 ....
Cb = .75 —.—
Cb = .80 —..—
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗

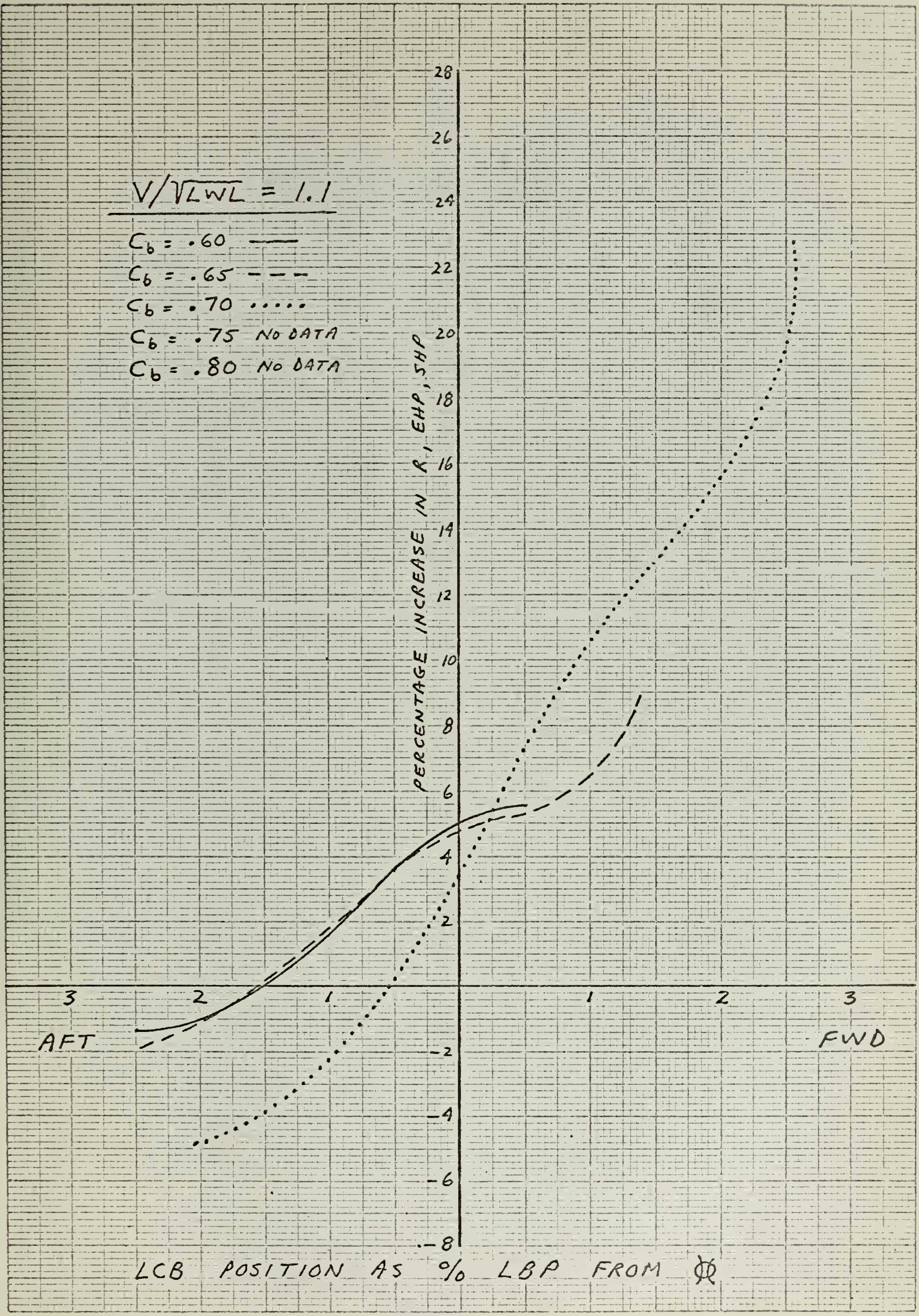

V/√LWL = 0.85
Cb = .60 ——
Cb = .65 - - -
Cb = .70 .....
Cb = .75 —•—
Cb = .80 —••—
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗


$V/\sqrt{L_{WL}} = 0.90$
C_b = .60 ——
C_b = .65 – – –
C_b = .70 · · · · ·
C_b = .75 —·—
C_b = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ℄


V/√LWL = 0.95
Cb = .60 ——
Cb = .65 - - -
Cb = .70 ·····
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM


V/√LWL = 1.0
Cb = .60 ——
Cb = .65 - - -
Cb = .70 .....
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊕


V/√LWL = 1.05
C_b = .60 ——
C_b = .65 - - -
C_b = .70 ·····
C_b = .75 NO DATA
C_b = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⊗


V/√LWL = 1.1
Cb = .60 ——
Cb = .65 – – –
Cb = .70 .....
Cb = .75 NO DATA
Cb = .80 NO DATA
PERCENTAGE INCREASE IN R, EHP, SHP
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-2
-4
-6
-8
3
2
1
1
2
3
AFT
FWD
LCB POSITION AS % LBP FROM ⌀

APPENDIX C

INSTRUCTIONS FOR USE OF THE EHP-SHP PROGRAM FOR SERIES 60

Page

1. Input deck for matrices $[A_{nl}]$ and $[B_{nl}]$ 75
2. Identification card 75
3. Input for ships 75
4. Loading of cards 77

1. Input deck for matrices $\left[A_{nl}\right]$ and $\left[B_{nl}\right]$

The input of matrices $\left[A_{nl}\right]$ and $\left[B_{nl}\right]$, a total of 900 elements, is accomplished by reading them from a deck of 180 cards, with 5 elements on each card, arranged in Format 5F16.7. See Appendix A for their proper arrangement.

Total no. of cards = 180

2. Identification card

In columns 1 - 4, (NJOBS),	Punch the integer number of ships to be calculated in this particular run, with the units digit of the integer in column 4. Format I4.
In columns 5 - 80, (QQ)	Punch any identification information desired. Example: "SCHUYLER OTIS BLAND TEST RUN." Format 19A4.

Total no. of cards = 1

3. Input for Ships

a. If input Mode I is being used for a ship, punch the following 3 cards for each ship:

Card 1

In columns 1 - 4, (INOPT),	Punch a positive integer. Example: "+5". Format I4.

Card 2

In columns 1 - 10, (XLBP),	Punch the length between perpendiculars in feet. Example: "400.0" Format F10.2.
In columns 11 - 20, (BM),	Punch the maximum beam at the load water line in feet. Example: "66.0". Format F10.2.
In columns 21 - 30, (H),	Punch the draft in feet. Example: "27.0". Format F10.2.
In columns 31 - 40, (CB),	Punch the block coefficient. Example: "0.651". Format F10.2.
In columns 41 - 50, (VMIN),	Punch the lowest speed in knots for which you desire information on EHP and SHP. Example: "8.557". Format F10.2

In columns 51 - 60, (VMAX),	Punch the highest speed in knots for which you desire information on EHP and SHP. Example: "19.25". Format F10.2.
In columns 61 - 70, (VINC),	Punch the increment of speed at which you wish information on EHP and SHP. Example: "1.07" Format F10.2.

Card 3

In columns 1 - 10, (DCF),	Punch the frictional ship correlation factor you desire to use. Example: ".0004". Format F10.2.
In columns 11 - 20, (XLCB),	Punch the position of LCB from ⊗ in feet, with a + sign if forward and a - sign if aft of ⊗ . Example: "- 4.0". Format F10.2.
In columns 21 - 30, (WSURF),	Punch the wetted surface area in square feet. Example: "39994.0". Format F10.2. If wetted surface is not known, punch a "0.0" in this space and the program will calculate it.
In columns 31 - 40, (RHO),	Punch the density of water in lb. sec^2/ft.^{4} at the temperature desired. Example: "1.9905". Format F10.2.
In columns 41 - 50, (GNU),	Punch the kinematic viscosity in ft.^{2}/sec. Example: "1.2817E-05", for 1.2817 x 10^{-5}. Format E10.2.

Note: If information on EHP and SHP is desired for only one speed for the ship, e.g. service speed, on card 2 punch this speed in the spaces for VMIN and VMAX, and punch "0.0" in the space for VINC.

Total no. of cards = NJOBS x 3.

b. If input Mode II is being used for a ship, follow the instructions for Mode I above with the following exceptions:

Card 1

In columns 1 - 4, (INOPT),	Punch a negative integer. Example: "-5". Format I4.

Card 2

In columns 11 - 20, (BH),	Punch the beam to draft ratio. Example: "2.5". Format F10.2
In columns 21 - 30, (DEL),	Punch the displacement in tons. Example: "10000.0". Format F10.2.

In columns 31 - 40, (CP), Punch the prismatic coefficient. Example ".612". Format F10.2.

Card 3

Identical to Mode I.

Mode I and Mode II input ships can be mixed at will as long as the cards are punched as above.

Graphs for making corrections to the computer output for variation in LCB position are contained in Appendix B.

4. Loading of cards

The cards are loaded in the following order:

1. Main EHP-SHP Program Deck
2. Subroutine CEF
3. Input deck for matrices $[A_{nl}]$ and $[B_{nl}]$
4. The identification card
5. Input cards for ships.

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